Edulab :
Majalah Ilmiah Laboratorium Pendidikan
https://ejournal.uin-suka.ac.id/tarbiyah/index.php/edulab/index

EISSN: 2527-7200
Vol. 10, No. 2, December 2025
DOI: https://doi.org/10.14421/edulab.2025.102.03

Rice husk waste characterization: Absorption and absorbance properties for potential renewable energy applications

Zulpadrianto✉
Universitas Islam Negeri Imam Bonjol Padang, Indonesia
Yeni Etma Nazar
Universitas Riau, Indonesia
Faisal Hariman Lubis
Universitas Islam Negeri Sultan Syarif Kasim Riau, Indonesia
Nur Aisyah Ali
Universitas Islam Negeri Imam Bonjol Padang, Indonesia

ABSTRACT

Purpose – This study aims to characterize rice husks as a renewable energy source. It measures the absorption and absorbance of rice husk waste. It determines the factors that affect the efficiency of rice husks (RHS) as a renewable energy source.

Design/methods/approach – Laboratory experiments and literature reviews were the methods used in this study. Material characterization was performed using a Vector Network Analyzer (VNA) to measure electromagnetic wave absorption and a UV-VIS spectrometer to measure UV absorption.

Findings – The results of the VNA measurement of RHS HCl 0M carbon = -3.80 dB; 1M = -13.28dB, and 3M = -12.28 dB. Absorbance measurements were then performed using UV-Vis. Based on the measurements performed, the absorbance values of each material were as follows: RH HCl 0M = 0.187 AU; 1M = 0.084 AU; 3M = 0.141 AU.

Research implications/limitations – Exploring the potential of rice husks as an environmentally friendly and sustainable renewable energy source. Analyzing the physical and chemical characteristics of rice husks, including their carbon content, to determine the energy efficiency that can be generated through various conversion technologies such as combustion, activation, and measurement.

Originality/value – This study focuses on the potential of rice husks as a renewable energy source.

OPEN ACCESS

ARTICLE HISTORY
Received: 22-11-2025
Revised: 27-12-2025
Accepted: 28-12-2025

KEYWORDS
Research laboratory,
Renewable energy.
Rice husks

CONTACT: ✉zulpadrianto@uinib.ac.id

Introduction

Electricity has become a primary need for the global community (Kabeyi & Olanrewaju, 2022). This need should be accompanied by new discoveries that are inexpensive, environmentally friendly, and effective to use (Bradu et al., 2022). Solar cells are one solution that can be used to maintain energy stability (Łysień et al., 2022). With the advancement of science, an optimal raw material for solar cells has been discovered, namely selenium (a semiconductor), which has photoconductivity properties (Alwadai et al., 2022).

Semiconductor materials are materials that have properties between conductors and insulators (Łysień et al., 2022). A characteristic property of semiconductor materials is their ability to conduct electric current under certain conditions and have higher resistivity than conductors (P. Zhang et al., 2024). Semiconductor materials also have valence bands and conduction bands (Siu, 2022). Electric current can flow through semiconductor materials when electrons from the valence band are transmitted to the conduction band. When the ambient temperature increases, the electrons in the material have enough energy to jump to the conduction band, making the semiconductor more conductive (Rahayu, 2022).

Natural semiconductor materials include silicon, AlGaAs, GaN, InP, ZnSe, CdTe, and CIGs (Malik et al., 2010) *and* (A. Du et al., 2022). Silicon is a chemical element with the symbol Si and atomic number 14 in the periodic table of elements (Pastuszak & Węgierek, 2022). Silicon can be found in organic materials (Nora Dwy, 2023). Based on XRF testing, rice husks contain 80.4% silica (SiO2) (Aprida, 2018). Other studies confirm that the silica content in rice husks is greater than 80%, ranging from 87% to 97% (Sandya et al., 2019). In addition to their high silica content, rice husks also exhibit strong electromagnetic (EM) absorption (Zulpadrianto et al., 2018).

Furthermore, due to the abundance of rice husks and their unique chemical properties, several researchers have conducted critical reviews of the processing and application of rice husks to produce various silicon-based and activated carbon materials. The discussion covers processing methods, the influence of various parameters on the pyrolysis stage, and the role of physical, chemical, and thermal treatments in the activation and consolidation mechanisms of activated carbon (Zulpadrianto et al., 2018). In addition, a flow chart illustrates the various SiO2 production pathways (Soltani et al., 2015). Further research relates to the physical, chemical, and morphological characteristics of rice husk ash and the effect of rice husk combustion conditions on these characteristics—the use of rice husk ash as a binding material. The use of rice husk ash has been proven to significantly increase the durability of concrete (Singh, 2018).

The development of local biomass resources remains an important strategy for supporting sustainable energy systems, particularly in agricultural waste management. Rice husk waste is abundantly available and has been widely studied for its potential use in energy-related applications; however, previous studies have predominantly focused on its role as a fuel or energy source, while the fundamental material characteristics that underpin such applications have not been sufficiently addressed. In particular, systematic and quantitative investigations of the absorption and absorbance properties of rice husks, which are critical for assessing their functionality as an absorber material, remain limited. Addressing this gap is essential, as a clear understanding of these properties constitutes a necessary scientific basis before advancing toward direct energy conversion applications.

Therefore, the present study focuses on the characterization of rice husk waste as an absorber material by analyzing its absorption and absorbance behavior, along with relevant physical and chemical characteristics. By providing measurable and experimentally grounded insights, this study aims to contribute a foundational reference for the potential utilization of rice husks in future renewable energy (Tjiwidjaja & Salima, 2023) and sustainability-oriented applications, while indirectly supporting efforts to reduce agricultural waste, dependence on fossil energy, and greenhouse gas emissions (Wibowo, 2024).

Methods

Laboratory experiments were conducted as part of this research (Anantasia & Rindrayani, 2025). This approach focuses on innovation and the development of technologies based on local materials that have the potential to support the development of renewable energy. This research uses rice husk materials. These materials were chosen for their abundant availability, low cost, and potential as renewable energy sources. By utilizing these local materials, it is hoped that solutions can be provided that are not only environmentally friendly but also sustainable for the community.

The laboratory experiments used in this study referred to the steps of experimental research and design (Setiyo & Waluyo, 2025). The research was conducted at three locations: the Physics Laboratory of the Faculty of Tarbiyah and Teacher Training at UIN Imam Bonjol Padang, the Physics Laboratory of Padang State University, and the Chemistry Laboratory of UIN Sultan Syarif Kasim Riau. The locations were chosen because they had adequate facilities to carry out all stages of the research.

The research stages began with a preliminary study that included a literature review of rice husk materials and a needs analysis (Akhter et al., 2023). This study aims to understand the characteristics of rice husks and their potential in renewable energy. After the preliminary study, the research progressed to the characterization of rice husks. This stage included several main steps, as follows:

1. Carbonization is carried out at a temperature of 110 °C (Saha et al., 2023; Z. Wang et al., 2023). The carbonized material is then activated using 1 Molar and 3 Molar HCl solutions (Dharmarajan et al., 2024). Activation is carried out to ensure that the material can support energy conversion efficiency (Wei et al., 2023).
2. Physical and Chemical Testing: The activated material is tested using a Vector Network Analyzer (VNA) to measure electromagnetic wave absorption and a UV-Vis spectrometer to determine the energy gap. This test aims to ensure that the material's chemical composition meets the standards required for renewable energy applications.

This study employed a purely experimental, characterization-based research design to evaluate the intrinsic material properties of rice husk–derived carbon as an absorber material. Rice husk samples were cleaned, dried, and ground to a particle size of 100–200 μm to ensure material homogeneity. Carbonization was conducted at 110 °C for 2 hours, a temperature selected to induce an initial structural transformation while preserving key organic components, as reported in previous studies of biomass-based materials. Chemical activation was performed with 1 M, 2 M, and 3 M hydrochloric acid (HCl) solutions, allowing evaluation of different activation intensities. For each condition, 20 g of carbonized material was immersed in the activating solution and stirred continuously for 1 hour to promote uniform acid–carbon interaction. The samples were then precipitated for 48 hours, washed with distilled water until the pH reached 6–7, filtered, and dried at 110 °C for 2 hours to obtain activated carbon.

Electromagnetic absorption characteristics were assessed by measuring the reflection coefficient with a Vector Network Analyzer (VNA) E5071C ENA series, operating over a frequency range of 9 kHz to 20 GHz. Measurements were conducted using a waveguide system with dimensions of 10 × 30 mm, and the activated carbon samples were molded into absorber specimens with a uniform thickness of 10 mm, chosen to ensure sufficient interaction between the incident electromagnetic waves and the absorber material. Complementary optical absorbance and energy gap analyses were performed using UV–Vis spectroscopy. This methodological approach provides a controlled, reproducible framework for evaluating the absorption-related properties of rice husk–based materials, serving as a foundation for future application-oriented studies.

Result

Research on the potential of rice husks as renewable energy has been conducted, both through experimental research and literature reviews. The following is an explanation of the results of the research that has been carried out.

1. Characterization of Rice Husks (RHS)

RHS silica is a sustainable, environmentally friendly, economical, and versatile alternative to conventional silica sources. Among various methods of extracting silica from RHS, acid leaching produces silica with higher purity, while new techniques such as the hydrothermobaric process are specifically capable of producing high-purity nanosilica. (Taiye et al., 2024). Despite challenges such as limited access to high-quality rice husks and variations in silica content in husks, the RHS extraction method shows promising prospects for sustainable silica production while addressing waste management and environmental issues (Taiye et al., 2024). The silica content in rice husks can be used as a natural power generator by transferring the heat energy produced (Steven et al., 2023).

Special properties of silica such as surface area, size, biocompatibility, and high functionality (September et al., 2023). Silica production from industrial agricultural waste demonstrates sustainability and potential for waste reduction (September et al., 2023). Although considered waste, it can be a useful component for sustainable progress and further technological development. In green synthesis, significant efforts have been made to replace toxic chemicals and reduce energy consumption with the same amount and quality of silica. Methods for reducing silica to silicon are also discussed, with specific properties that have potential applications in electronic devices, as well as modern technologies such as batteries, supercapacitors, and solar cells (September et al., 2023).

2. Electromagnetic Wave Absorption Capacity of Rice Husks

Measurements of the electromagnetic wave absorption value of rice husks using a Vector Network Analyzer (VNA) show the ability of RHS to absorb electromagnetic waves, as shown in Table 1.

Table 1

Results of EM wave absorption measurements of activated rice husk carbon with varying HCl activation agents.

Concentration	Reflection Loss(dB)	Reflection Coefficient	Absorption
0 M	-3,80	0,42	58%
1 M	-13,28	0,05	95%
3 M	-12,28	0,06	94%

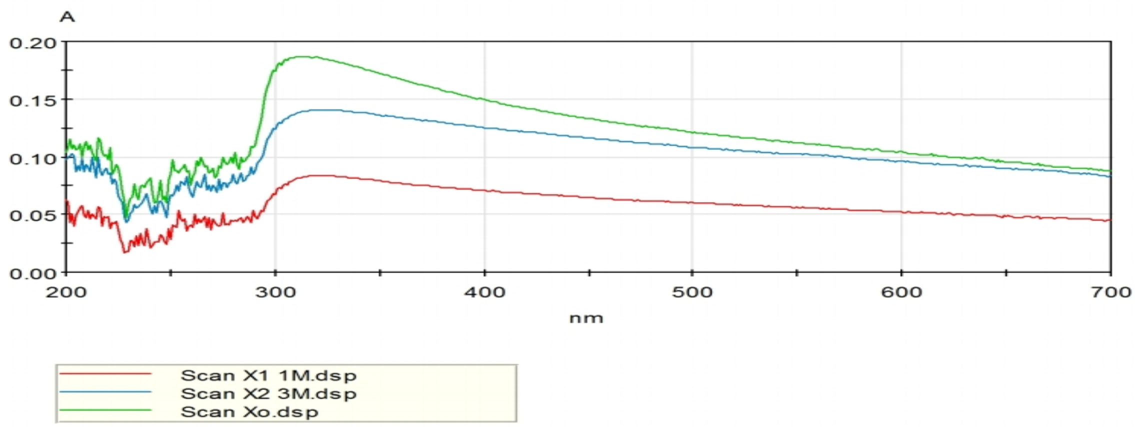
Table 1 shows the differences in carbon absorption capacity of RHS activated with varying concentrations of HCl. Under non-activated conditions (0 M), the reflection loss value was -3.80 dB with a reflection coefficient of 0.42, resulting in an energy absorption capacity of 58%. Activation using a 1 M HCl concentration resulted in a reflection loss of -13.28 dB with a reflection coefficient of only 0.05. Furthermore, when the HCl concentration was increased to 3 M, the absorption capacity of activated carbon from RHS actually decreased slightly compared to the 1 M treatment. The reflection loss value was recorded at -12.28 dB with a reflection coefficient of 0.06.

3. Ultraviolet Absorbance Value of Rice Husks.

In this study, measurements were taken of the absorbance of biomass waste in the form of RHS that had been processed into activated carbon through an activation process with varying concentrations of HCl. The main purpose of these measurements was to determine the material's ability to absorb UV energy, particularly when tested using the UV-Vis spectrophotometry method in the wavelength range of 200–700 nm (T. Wang et al., 2025). High absorbance indicates the material's ability to absorb energy better (B. Wang et al., 2023). Thus, it has great potential to be used as a renewable and sustainable energy source.

Figure 1

Graph of RHS carbon measurement results using a UV-Vis spectrometer



Measurements using a UV-Vis spectrophotometer on activated carbon derived from rice husks (RHS) with varying HCl activation showed differences in absorbance patterns in the 200–700 nm wavelength range. The three curves obtained illustrate the differences in material characteristics based on the chemical treatment applied. The sample without activation (X0) is shown by the green curve, 1 M HCl activation (X1) by the red curve, while 3 M HCl activation (X2) is illustrated by the blue curve. In general, it can be observed that the unactivated sample shows the highest absorbance value, with a peak approaching 0.20 at a wavelength of around 300 nm. This indicates that RHS has natural functional groups, such as silica and organic compounds, which are still quite dominant in absorbing ultraviolet light energy. Meanwhile, the activated samples show a lower absorbance pattern, indicating a significant change in the material structure. This difference provides an initial indication that chemical activation plays an important role in changing the optical properties of activated carbon, as well as affecting its ability to absorb light and electromagnetic waves.

The RHS sample activated with 1 M HCl (X1) showed a relatively low absorbance value compared to the other two samples, with a maximum of only about 0.09. This indicates that the chemical activation process was able to dissolve impurities and remove most of the functional groups that initially contributed to the absorbance. With the reduction of these light-absorbing groups, the pore structure of the activated carbon becomes more open and regular. The decrease in absorbance does not mean that the material loses its overall absorptive capacity, but rather indicates an improvement in optical properties towards a more stable condition for non-optical applications. 1 M activation can be considered the optimum condition for forming the character of RHS activated carbon. Although its absorbance is low, this is closely related to the increase in surface area and pore regularity, which are more conducive to absorbing electromagnetic waves. Therefore, this significant change not only shows the effect of dissolution but also the process of engineering the internal structure of the material, leading to better performance in the context of renewable energy.

In the RHS sample with 3 M HCl activation (X2), the absorbance value was between the two previous conditions, with a peak of around 0.14. Although the result was lower than the sample without activation, the higher absorbance compared to 1 M activation indicated a balance between impurity dissolution and excessive erosion of the pore structure. Too high a concentration of HCl can damage part of the pore walls, thereby reducing the regularity of the material structure. However, the absorbance value, which is still quite significant, indicates that samples with 3 M activation still retain the ability to absorb large amounts of light energy. Overall, these UV-Vis measurement results show a trend that chemical activation with HCl has a significant effect on the optical properties of RHS activated carbon, with a concentration of 1 M providing the most stable conditions. The changes in absorbance values shown by the curve not only reflect optical properties but are also related to the material's ability to absorb non-optical energy, including electromagnetic waves. Thus, this study supports the idea that RHS waste can be developed as a sustainable renewable energy material through appropriate chemical activation processes.

Discussion

The use of rice husk biomass as a raw material for activated carbon for renewable energy applications reflects a sustainable, economical, and environmentally friendly approach (Akhter et al., 2023). Indonesia, as an agricultural country, produces millions of tons of rice husk waste every year (Wahditiya et al., 2025). Rice husks are a by-product of rice milling, accounting for 20% of the weight of paddy rice, which has been mostly discarded or used only as traditional solid fuel (Ramírez et al., 2024). Characterization of the physical and chemical properties of this biomass provides an in-depth picture of its potential as a renewable energy material (Arshad & Moin, 2025).

In the current development of science and technology, the issues of renewable energy and sustainability are becoming a major concern, along with the depletion of fossil fuel reserves and the negative impact of their use on the environment. One solution that has been widely studied is the use of biomass waste as a raw material to produce functional materials with high added value (Kammen, 2006). The silica and activated carbon content of this waste has a large pore structure, making it effective as an electromagnetic wave absorber (Zulpadrianto et al., 2018).

Table 1 data shows the difference in carbon absorption capacity of RHS activated with varying concentrations of HCl. Under non-activated conditions (0 M), the reflection loss value only reached -3.80 dB with a reflection coefficient of 0.42, resulting in an energy absorption capacity of 58%. This value indicates that activated carbon from RHS that has not undergone chemical treatment still has limited porosity and surface area, making it less effective at absorbing waves. This shows that the chemical activation process with HCl plays an important role in improving the absorption quality of activated carbon.

Activation treatment using 1 M HCl concentration significantly improves the absorption capacity of activated carbon. Under these conditions, reflection loss reaches -13.28 dB with a reflection coefficient of only 0.05, which means that almost all waves are absorbed. The absorption percentage reaches 95%, which is much higher than samples without activation. These results indicate that the use of a 1 M HCl concentration for RHS activation can increase EM wave absorption by 37%.

Interestingly, when the HCl concentration was increased to 3 M, the absorption capacity of activated carbon from RHS actually decreased slightly compared to the 1 M treatment. The reflection loss value recorded was -12.28 dB with a reflection coefficient of 0.06, and the absorption percentage decreased to 94%. Although this value is still relatively high, the results show that too high a concentration of HCl can cause damage to some of the activated carbon pore structure, thereby reducing its absorption effectiveness.

In the non-activated condition, the relative low absorption of RHS EM waves is caused by the limitations of natural porosity and the presence of impurities in the material. However, after activation treatment with HCl, there was a significant increase in energy absorption capacity (Shahcheragh et al., 2023). This can be seen from the decrease in the reflection coefficient value and the increase in the absorption percentage value of activated carbon. Activation with a certain concentration of HCl, specifically 1 M, proved to be the optimum point that produced activated carbon with the highest absorption capacity when compared to activation using 3 molar HCl. This condition indicates that chemical treatment can effectively improve the pore structure of biomass material (Yin et al., 2023). With increased material porosity, its ability to absorb electromagnetic wave energy is enhanced (J. Du et al., 2023). Activated carbon produced from RHS after undergoing activation treatment using HCl solutions with varying concentrations shows potential as an energy source (Arshad & Moin, 2025).

Furthermore, when measurements were taken using UV-Vis at wavelengths of 200-700 nm (UV light), the results showed differences in absorbance values for each sample with different activator concentrations. RHS showed a tendency for increased absorbance at certain concentrations, although there were variations in the absorption peaks characteristic of each material. This indicates that the pore structure, surface area, and activated carbon content produced are greatly influenced by the concentration of the activating agent used (Rianto et al., 2019).

Conclusion

Based on the results of this study, it can be concluded that rice husk waste exhibits favorable absorption and absorbance properties in the microwave and ultraviolet regions, indicating its potential as a functional absorber material for renewable energy–related applications. Among the investigated activation conditions, chemical activation using HCl at a concentration of 1 M provided the optimum performance, as reflected by enhanced electromagnetic wave absorption and more stable optical absorbance characteristics compared to higher acid concentrations. These findings confirm that controlled activation plays a crucial role in tailoring the absorber properties of rice husk–derived carbon. While the observed absorption behavior suggests potential applicability in energy conversion–supporting components (Jung & Hull, 2023), such as electromagnetic absorbers (Steven et al., 2023) and photovoltaic-related materials (Z. Zhang et al., 2023), the present study is limited to material characterization and does not directly assess energy generation performance (Jung & Hull, 2023). Future research should therefore focus on thickness- and frequency-dependent absorption analysis, long-term material stability, and integration of rice husk–based absorbers into prototype energy devices to further validate their practical potential.

Declarations

Author contribution statement

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts form.

Funding statement

This research is part of a research grant from Imam Bonjol State Islamic University, Padang.

Data availability statement

The processed data supporting the findings of this study are included in the article. Raw experimental data are available from the corresponding author upon reasonable request for academic and research purposes.

Declaration of interests statement

This research is a capacity building cluster research at Imam Bonjol State Islamic University, Padang and without any conflict of interest.

Additional information

This study is part of an ongoing research effort focused on the characterization and utilization of rice husk waste as a functional material for renewable energy related applications. The authors welcome scholarly discussion, critical feedback, and collaborative research specifically related to rice husk derived materials, absorption and absorbance properties, and biomass-based energy applications. Further information regarding this study and related research may be obtained by contacting the corresponding author via email.

References

Akhter, F., Soomro, S. A., Jamali, A. R., Chandio, Z. A., Siddique, M., & Ahmed, M. (2023). Rice husk ash as green and sustainable biomass waste for construction and renewable energy applications: A review. *Biomass Conversion and Biorefinery, 13*(6), 4639–4649. https://doi.org/10.1007/s13399-021-01527-5

Alwadai, N., Elqahtani, Z. M., Khan, S. U., Pembere, A. M. S., Badshah, A., Mehboob, M. Y., & Nazar, M. F. (2022). Impact of halogens on electronic and photovoltaic properties of organic semiconductors: A multiscale computational modeling. *Journal of Physical Organic Chemistry, 35*(8), e4388. https://doi.org/10.1002/poc.4388

Anantasia, G., & Rindrayani, S. R. (2025). Metodologi penelitian quasi eksperimen. *ADIBA: Journal of Education, 5*(2), 183–192.

Aprida, L. F. (2018). *Pemanfaatan kandungan CaO limbah karbit dan kandungan silika abu sekam padi sebagai bahan pembuatan bata beton pejal* [Diploma thesis, Politeknik Perkapalan Negeri Surabaya]. http://repository.ppns.ac.id/1477/

Arshad, H., & Moin, A. (2025). Physical and chemical properties of rice husk. In M. Jawaid & B. Parmar (Eds.), *Rice husk biomass* (pp. 27–42). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-1082-2_2

Bradu, P., Biswas, A., Nair, C., Sreevalsakumar, S., Patil, M., Kannampuzha, S., Mukherjee, A. G., Wanjari, U. R., Renu, K., Vellingiri, B., & Gopalakrishnan, A. V. (2022). RETRACTED ARTICLE**:** Recent advances in green technology and Industrial Revolution 4.0 for a sustainable future. *Environmental Science and Pollution Research, 30*(60), 124488–124519. https://doi.org/10.1007/s11356-022-20024-4

Dharmarajan, N. P., Vidyasagar, D., Yang, J., Talapaneni, S. N., Lee, J., Ramadass, K., Singh, G., Fawaz, M., Kumar, P., & Vinu, A. (2024). Bio-inspired supramolecular self-assembled carbon nitride nanostructures for photocatalytic water splitting. *Advanced Materials, 36*(2), 2306895. https://doi.org/10.1002/adma.202306895

Du, A., Li, H., Chen, X., Han, Y., Zhu, Z., & Chu, C. (2022). Recent research progress of silicon-based anode materials for lithium-ion batteries. *ChemistrySelect, 7*(19), e202201269. https://doi.org/10.1002/slct.202201269

Du, J., Li, T., Xu, Z., Tang, J., Qi, Q., & Meng, F. (2023). Structure–activity relationship in microstructure design for electromagnetic wave absorption applications. *Small Structures, 4*(11), 2300152. https://doi.org/10.1002/sstr.202300152

Jung, C. G., & Hull, R. F. C. (2023). On psychic energy. In *Collected works of C. G. Jung* (Vol. 8, pp. 3–66). Routledge. https://doi.org/10.4324/9781032652047-140

Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Sustainable energy transition for renewable and low-carbon grid electricity generation and supply. *Frontiers in Energy Research, 9*, 743114. https://doi.org/10.3389/fenrg.2021.743114

Kammen, D. M. (2006). The rise of renewable energy. *Scientific American, 295*(3), 84–93. 10.1038/scientificamerican0906-84

Łysień, M., Witczak, Ł., Wiatrowska, A., Fiączyk, K., Gadzalińska, J., Schneider, L., Stręk, W., Karpiński, M., Kosior, Ł., & Granek, F. (2022). High-resolution deposition of conductive and insulating materials at micrometer scale on complex substrates. *Scientific Reports, 12*(1), 9327. 10.1038/s41598-022-13352-5

Malik, M. A., Afzaal, M., & O'Brien, P. (2010). Precursor chemistry for main group elements in semiconducting materials. *Chemical Reviews, 110*(7), 4417–4446. https://doi.org/10.1021/cr900406f

Nora Dwy, S. (2023). *Analisis efektivitas metode gravity-fed filtering system pada pengolahan kualitas air di Desa Pringgabaya Kabupaten Lombok Timur* [Doctoral dissertation, Universitas Mataram]. http://eprints.unram.ac.id/id/eprint/41642

Pastuszak, J., & Węgierek, P. (2022). Photovoltaic cell generations and current research directions for their development. *Materials, 15*(16), 5542. https://doi.org/10.3390/ma15165542

Rahayu, S. U. (2022). *Aplikasi semikonduktor Wittichenite (Cu_3BiS_3) pada sel surya tipe quantum dot-sensitized solar cells (QD-SSCs)*. Penerbit NEM.

Ramírez, A. T. O., Tovar, M. R., & Silva-Marrufo, O. (2024). Rice husk reuse as a sustainable energy alternative in Tolima, Colombia. *Scientific Reports, 14*(1), 10391. 10.1038/s41598-024-60115-5

Rianto, D., Satria, N., Putra, A., & Sumantyo, J. T. S. (2019). Effect of activating agent on electromagnetic waves absorption of carbon-based radar absorber material. In *Proceedings of the 2019 Photonics & Electromagnetics Research Symposium–Spring* (pp. 1281–1283). IEEE. https://doi.org/10.1109/PIERS-Spring46901.2019.9017548

Saha, S., Islam, M. T., Calhoun, J., & Reza, T. (2023). Effect of hydrothermal carbonization on fuel and combustion properties of shrimp shell waste. *Energies, 16*(14), 5534. https://doi.org/10.3390/en16145534

Sandya, Y., Prihantono, & Musalamah, S. (2019). Penggunaan abu sekam padi sebagai pengganti semen pada beton geopolimer. *Educational Building: Jurnal Pendidikan Teknik Bangunan dan Sipil, 5*(2), Article 2. https://doi.org/10.24114/ebjptbs.v5i2

September, L. A., Kheswa, N., Seroka, N. S., & Khotseng, L. (2023). Green synthesis of silica and silicon from agricultural residue sugarcane bagasse ash: A mini review. *RSC Advances, 13*(2), 1370–1380. https://doi.org/10.1039/D2RA07490G

Setiyo, M., & Waluyo, B. (2025). *Metodologi penelitian dan perancangan eksperimen*. Unimma Press.

Shahcheragh, S. K., Bagheri Mohagheghi, M. M., & Shirpay, A. (2023). Effect of physical and chemical activation methods on the structure, optical absorbance, band gap, and Urbach energy of porous activated carbon. *SN Applied Sciences, 5*(12), 313. https://doi.org/10.1007/s42452-023-05559-6

Singh, B. (2018). Rice husk ash. In *Waste and supplementary cementitious materials in concrete* (pp. 417–460). Elsevier. https://doi.org/10.1016/B978-0-08-102156-9.00013-4

Siu, C. (2022). Semiconductor physics. In *Electronic devices, circuits, and applications* (pp. 35–39). Springer. https://doi.org/10.1007/978-3-030-80538-8_3

Soltani, N., Bahrami, A., Pech-Canul, M. I., & González, L. A. (2015). Review on the physicochemical treatments of rice husk for production of advanced materials. *Chemical Engineering Journal, 264*, 899–935. https://doi.org/10.1016/j.cej.2014.11.056

Steven, S., Restiawaty, E., & Bindar, Y. (2023). A simulation study on rice husk to electricity and silica mini-plant: From organic Rankine cycle (ORC) study to its business and investment plan. *Waste and Biomass Valorization, 14*(5), 1787–1797. https://doi.org/10.1007/s12649-022-01957-w

Taiye, M. A., Hafida, W., Kong, F., & Zhou, C. (2024). A review of the use of rice husk silica as a sustainable alternative to traditional silica sources in various applications. *Environmental Progress & Sustainable Energy, 43*(6), e14451. https://doi.org/10.1002/ep.14451

Tjiwidjaja, H., & Salima, R. (2023). Dampak energi fosil terhadap perubahan iklim dan solusi berbasis energi hijau. *Jurnal Wilayah, Kota dan Lingkungan Berkelanjutan, 2*(2), 166–172. https://doi.org/10.58169/jwikal.v2i2.625

Wahditiya, A. A., Semet, M. M., Nantan, Y., Istoto, E. H., Purnamasari, R., Maulana, A. P., Baali, Y., & Niati, S. M. (2025). *Energi dari limbah dan sampah: Teknologi, kebijakan, dan implementasi*. Yayasan Tri Edukasi Ilmiah.

Wang, B., Xu, C., Duan, G., Xu, W., & Pi, F. (2023). Review of broadband metamaterial absorbers: From principles, design strategies, and tunable properties to functional applications. *Advanced Functional Materials, 33*(14), 2213818. https://doi.org/10.1002/adfm.202213818

Wang, T., Wang, Q., Yin, H., Ye, Q., Zhang, H., Song, S., & Jia, F. (2025). In-situ 1T@2H MoS_2 with phase-doped arrays for full-spectrum solar absorption and high-performance solar desalination. *Chemical Engineering Journal*, 168163. https://doi.org/10.1016/j.cej.2025.168163

Wang, Z., Huang, J., Hu, W., Xie, D., Xu, M., & Qiao, Y. (2023). In-depth study of the sulfur migration and transformation during hydrothermal carbonization of sewage sludge. *Proceedings of the Combustion Institute, 39*(3), 3419–3427. https://doi.org/10.1016/j.proci.2022.07.184

Wei, D., Wang, C., Zhang, J., Zhao, H., Asakura, Y., Eguchi, M., Xu, X., & Yamauchi, Y. (2023). Water activation in solar-powered vapor generation. *Advanced Materials, 35*(47), 2212100. https://doi.org/10.1002/adma.202212100

Wibowo, K. (2024). Kontribusi pembangkit listrik energi terbarukan dalam mengurangi emisi karbon. *Innovative: Journal of Social Science Research, 4*(6), 5140–5153. https://doi.org/10.31004/innovative.v4i6.16043

Yin, Y., Liu, Q., Zhao, Y., Chen, T., Wang, J., Gui, L., & Lu, C. (2023). Recent progress and future directions of biomass-derived hierarchical porous carbon: Designing, preparation, and supercapacitor applications. *Energy & Fuels, 37*(5), 3523–3554. https://doi.org/10.1021/acs.energyfuels.2c04093

Zhang, P., Zhu, B., Du, P., & Travas-Sejdic, J. (2024). Electrochemical and electrical biosensors for wearable and implantable electronics based on conducting polymers and carbon-based materials. *Chemical Reviews, 124*(3), 722–767. https://doi.org/10.1021/acs.chemrev.3c00392

Zhang, Z., Chen, M., Zhong, T., Zhu, R., Qian, Z., Zhang, F., Yang, Y., Zhang, K., Santi, P., & Wang, K. (2023). Carbon mitigation potential afforded by rooftop photovoltaic in China. *Nature Communications, 14*(1), 2347. https://doi.org/10.1038/s41467-023-38079-3

Zulpadrianto, Z., Yohandri, Y., & Putra, A. (2018). Development of radar absorber material using rice husk carbon for anechoic chamber applications. *IOP Conference Series: Materials Science and Engineering, 335*(1), 012002. https://doi.org/10.1088/1757-899X/335/1/012002