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Optimization of Cascara Briquettes for Renewable Energy Production through Thermoelectric Generators as an Extension of the RBL-STEM Model in Enhancing Students' Creative Thinking Skills

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Abstract: The global fossil fuel crisis and demand for sustainable renewable energy sources have driven the development of biomass-based alternative fuels. Cascara, a coffee husk by-product with high cellulose content and wide availability, has strong potential for conversion into biomass briquettes; however, improvements in fuel quality and energy conversion efficiency are needed. This study aims to improve the physical, thermal, mechanical, and emission performance of cascara briquettes by varying the composition of cascara leaves, bletong, and Tectona grandis, as well as integrating the optimized briquettes as a heat source in a thermoelectric generator (TEG) system. This study also evaluates the effectiveness of applying a STEM-based Research-Based Learning (RBL-STEM) model in improving students' creative thinking skills. This study was conducted in two stages. The experimental stage used a completely randomized design with ten briquette formulations and tested the calorific value, combustion rate, impact strength, and emissions. The learning stage applied the research results to 35 students using a single-group pretest-posttest design. The data were analyzed using instrument validation, normality tests, correlation analysis, and paired sample t-tests. The best formulation (70:20:10) produced the highest calorific value, while 50:30:20 produced the lowest emissions. The implementation of RBL-STEM significantly improved students' creative thinking performance.

Keywords: Cascara briquettes; Creative thinking skills; RBL-STEM; Thermoelectric generator

Introduction

The fossil fuel crisis and its environmental impact are increasingly driving the development of clean and renewable energy sources based on the circular economy (US EIA, 2025). Biomass has emerged as a strategic renewable energy source due to its abundant availability, renewable nature, and potential to produce high-calorie solid fuels. Conventional biomass briquettes have been produced from various materials such as rice husks, sawdust, and agricultural waste (Patil, 2019), but still face obstacles in the form of low energy density, high combustion emissions, dependence on seasonal raw materials, and the need for relatively complex and expensive production processes. These conditions underscore the need for innovation in raw material selection and processing in order to improve the quality of the energy produced

In this context, the utilization of coffee husks is highly relevant, given that Indonesia is one of the

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world's largest coffee producers with enormous potential for organic waste. The physical and chemical characteristics of coffee residue, including moisture and ash content, allow for an increase in calorific value as shown in other biomass such as coconut husks and cocoa shells (Fitriyano et al., 2023; Mustafa et al., 2023; Tesfaye et al., 2022). Previous studies have reported that the calorific value of biomass briquettes can reach 16.6–22 MJ/kg (Lubwama et al., 2020), and coffee husks themselves have a high cellulose content of 59.32%, making them suitable for development as an alternative energy source (Anggono et al., 2023). The use of bagasse not only meets the need for renewable energy but also offers a solution for sustainable agricultural waste management (Cruz et al., 2021). However, the energy conversion efficiency of briquette combustion remains a challenge. One approach to overcome this is by adding bagasse, which is high in carbohydrates and fiber and has a calorific value of up to 4000–5000 cal/g (Komaria et al., 2020). Other studies show that carbon-rich materials such as bagasse can improve combustion stability and energy efficiency (Dione et al., 2025). Thus, cascara briquette formulations with added bagasse have the potential to improve combustion quality while reducing emissions.

The conversion of combustion heat into electrical energy is also an important focus in efforts to improve energy efficiency. Thermoelectric generators (TEGs) offer an effective solution for converting heat energy into electrical energy through the Seebeck effect, whereby the temperature difference between the hot and cold sides generates electrical voltage (Joy et al., 2024). TEG efficiency is influenced by material factors such as the Seebeck coefficient and thermal conductivity (Roman & Grzegorzewska, 2024), as well as optimal temperature gradient settings (Erdiyanto et al., 2024). TEG applications are ideal for remote areas because they are self-contained, have no moving parts, and require minimal maintenance, making them suitable for small-scale applications such as LED lights, batteries, and sensors (Aridi et al., 2021). The integration of TEGs in biomass combustion systems has been shown to increase the utilization of waste heat energy (Pratama et al., 2023), especially when the modules are strategically placed and equipped with an efficient heat exchanger design (Jouhara et al., 2021; Van Toan et al., 2022). In addition to technical aspects, sustainability evaluations such as life cycle analysis (LCA), particulate emissions, and socioeconomic impacts are also important (Rashif et al., 2025; Saba et al., 2020).

In the field of education, the use of renewable energy projects such as cascara briquettes and TEG can be integrated through the STEM-based Research-Based Learning (RBL-STEM) model. This approach emphasizes the integration of science, technology, engineering, and mathematics to produce authentic and contextual learning (Gibran et al., 2024). RBL-STEM encourages student involvement in the research stages, from problem identification to analysis of results, thereby improving critical thinking, creativity, collaboration, and digital literacy skills (Agatha et al., 2025; Junior et al., 2024; Ritli et al., 2022). Various studies have shown that RBL-STEM can improve innovation and problem-solving skills (Gita et al., 2023; Wulandari et al., 2025). In the context of local learning, this model can also integrate local wisdom and environmental issues, such as in the development of batik based on anti-magic coloring, which has been proven to increase students' visual creativity (Susanto et al., 2025). This shows that research-based learning can be adapted to various domains, including renewable energy technology.

Although various studies have discussed biomass briquettes, the use of cascara, the effectiveness of TEG, and the implementation of RBL-STEM learning, there are still gaps in research. No study has simultaneously developed cascara briquettes with added sugarcane bagasse and Tectona grandis leaves, utilized the heat from their combustion for TEG, and made them an RBL-STEM learning project to develop students' creative thinking skills. The novelty of this research lies in this multidisciplinary integration. Therefore, this study aims to optimize the formulation of cascara briquettes as a heat source for thermoelectric generators, test the performance of TEG in converting heat into electricity, and evaluate its contribution to enhancing student creativity through the RBL-STEM model. The urgency of this research includes renewable energy innovation, agricultural waste utilization, and strengthening 21st-century competencies in the educational environment.

Method

Research Subject and Time

The research on cascara briquette optimization and thermoelectric generator assembly was conducted at the UNIPAR biology laboratory and the Jember State Polytechnic from June to September 2025. Product testing was conducted on seventh-semester biology students at PGRI Argopuro University. This research began with the production and analysis of cascara briquettes, the assembly of thermoelectric generators, and quasi-experimental research using a one-group pretest-posttest design.

Optimization of Cascara Briquettes and Assembly of Thermoelectric Generators

This research was conducted at the Jember State Polytechnic laboratory and the PGRI Argopuro Jember biology laboratory. The cascara briquette optimization research design used a completely randomized design (CRD), with independent variables in the form of briquette raw material composition, namely the ratio of cascara, bletong, and Tectona grandis leaves in various formulations. The research sample consisted of 200 kg of dry coffee cascara divided into 10 groups, namely one control group and nine experimental groups, each weighing 20 kg, according to the designed formulation (Figure 1). The research variables included physical tests, thermal tests, energy, and the environment.

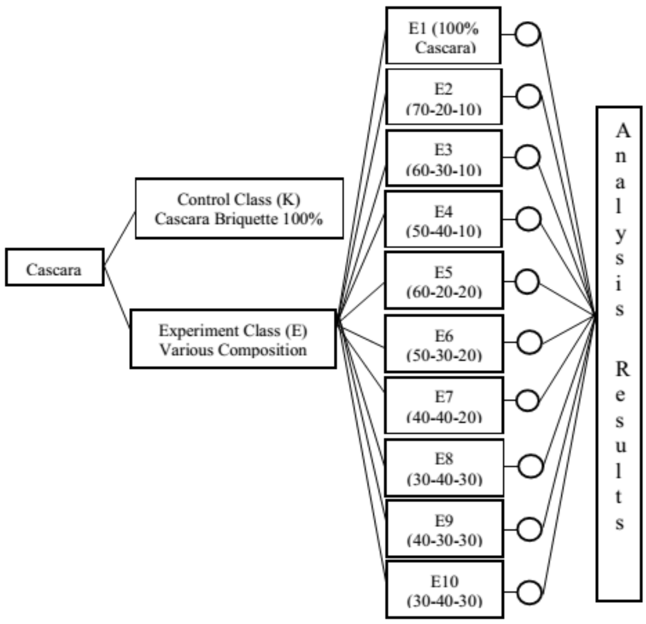

Figure 1. Details of the first study

Description:

◯	:	Data collection (Physical Tests, Thermal and Energy Tests, and Emission and Environmental Tests)
K	:	Control
E	:	Experimenting with various compositions

Research variables include: Physical tests: density, moisture content, and ash content; Thermal and energy tests: combustion rate, burning time, and combustion temperature stability; Environmental tests : smoke and odor measurements.

The thermoelectric generator is designed from an iron frame, Peltier module, and briquette heater, equipped with a USB socket. The tools and materials used include LEDs (10 pcs), cooling fans, DC voltmeters, cooling fins, batteries and battery boxes, cables, bolts, screws, furnaces, glue, thermal paste, iron plates, tin, and acrylic. All measurements were taken when the product was completed and when it was in use, following the research steps described in Figure 2.

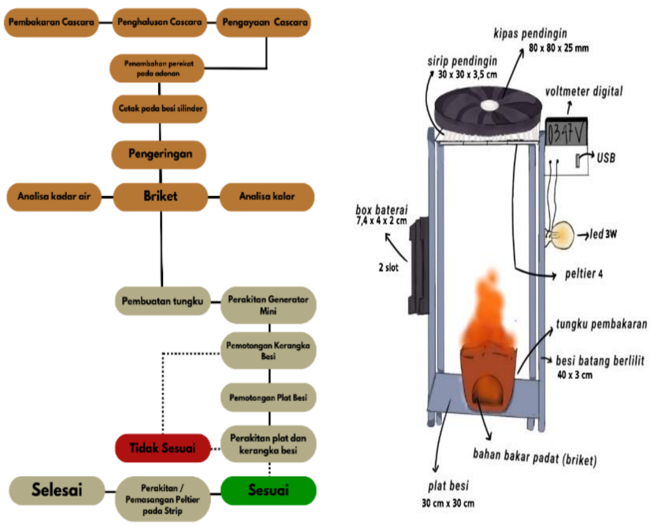

Figure 2. Research steps

Teaching Material Enhancement

The results of research on cascara briquette optimization for renewable energy production through thermoelectric generators are used as teaching materials in lectures. The development process uses the ADDIE Model design, which consists of five main steps, namely Analysis, Design, Development, Implementation, and Evaluation. A specific explanation of the ADDIE model in this study can be seen in the Table 1.

Table 1. ADDIE Model Stages

ADDIE Stage	Research Activities	Expected Results
Analysis	- Analyze research-based and STEM learning needs among biology students. - Identify the potential of coffee husks as an alternative biomass. - Assess the creative thinking skills that need to be improved.	Compilation of learning needs, research objectives, and the basis for selecting coffee husks as briquette material.
Design	- Designing an experiment to optimize cascara briquettes with varying compositions of materials (cascara, bletong, teak leaves). - Designing RBL-STEM-based learning tools using projects involving briquette production and thermoelectric generators. - Developing assessment tools (observation sheets, creative thinking skills tests).	Draft designs for experiments, learning tools, and assessment tools.
Development	- Create and test cascara briquettes with various formulations. - Assemble a thermoelectric generator using Peltier modules.	

ADDIE Stage	Research Activities	Expected Results
	- Develop and validate learning tools with the help of expert validators. - Revise products based on validator input.	Initial briquette products, thermoelectric generator prototypes, and validated learning tools.
Implementation	- Implementing RBL-STEM learning tools for fourth-semester Biology Education students. - Conducting project-based learning on cascara briquette optimization and thermoelectric generator testing. - Conducting pre-tests and post-tests on creative thinking skills.	Effective implementation of project-based RBL-STEM learning for students.
Evaluation	- Evaluate the practicality of the tool through observation of its implementation in learning. - Measure the effectiveness of the tool through analysis of students' creative thinking skills (fluency, flexibility, originality, elaboration). - Compile a report on the research results.	The learning tool is declared practical, effective, and capable of improving students' creative thinking skills.

During the analysis stage, problems related to renewable energy needs and the potential of coffee husks as raw material for briquettes were identified, while mapping student needs to develop STEM-based research skills. The design stage included the development of learning tools, testing instruments (physical, thermal, emissions, and environmental), and the design of a simple thermoelectric generator. The development stage focused on making cascara briquette prototypes with various formulations, assembling thermoelectric generators, developing support modules, and product validation by experts. Next, the implementation phase was carried out through the application of learning tools to fourth-semester Biology Education students in practical activities and STEM-based research projects. The final phase, evaluation, included an assessment of the validity, practicality, and effectiveness of the learning tools, with indicators of an increase in students' creative thinking skills.

The validity of the learning tools was analyzed using the average score from three validators with:

$$V = \frac{T_{SE}}{T_{SM}} x 100 \quad (1)$$

Explanation:
V = percentage of assessment level
TSE = total empirical score obtained
TSM = total maximum score

The percentage results are converted into qualitative categories: highly valid (81.25–100%), valid (62.5–81.25%), less valid (43.75–62.5%), and invalid (25–43.75%). The product is declared feasible for development if the validity is ≥62.5%, with the possibility of additional improvements, while substandard validity requires revision and revalidation until the learning tool reaches the ideal quality.

The practicality of the learning tools was assessed through testing the feasibility of the learning process using observation instruments by three observers. The average observer score was calculated using the following formula:

$$SR = \frac{ST}{SM} x\ 100\% \quad (2)$$

Explanation:
AS = Average observer score (in percent)
TS = Total score from observers
MS = Maximum score that can be obtained from the observation results

Effectiveness is measured by assessing creative thinking skills, including fluency, flexibility, originality, and elaboration. Creative thinking skills can be calculated using the following formula.

$$\text{Value} = \frac{\sum score\ obtained}{\sum maximum\ score}\ x\ 100\% \quad (3)$$

The measurement results were then classified into the following categories: very high (81.28–100), high (62.52–81.27), low (43.76–62.51), and very low (25–43.75).

Result and Discussion

Manufacturing Process of Cascara Briquettes

The cascara briquette production process began with the collection and preparation of raw materials, including harvesting teak leaves, collecting cascara, and obtaining sugarcane pulp from local sugar factories. Wet cascara was dried under direct sunlight before undergoing carbonization to produce cascara charcoal. After carbonization, each sample was weighed according to predetermined proportions and mixed with other required ingredients. The mixtures were then ground using a machine to achieve a smooth and uniform texture. Once the dough reached the appropriate consistency, it was molded into briquette form, cut to size, and transferred to drying trays. The molded briquettes were sun-dried until they reached a stable texture and were ready for further testing. These stages are documented in Figure 3.

Harvesting teak leaves; Taking sugarcane pulp at the sugar factory; Collecting cascara; Drying wet cascara under the hot sun; The process of carbonizing cascara into cascara charcoal; Weighing samples according to regulations; Mixing several necessary ingredients; Smooth out several ingredients with a machine; The result of mixing the dough that is ready to be molded; Briquette printing process; Cutting briquettes to size; Moving briquettes onto the drying tray; Drying briquettes under the hot sun; The briquettes are ready for use in further research.

Figure 3. The process of making cascara briquettes

Assembly of the Thermoelectric Generator (TEG) System

The thermoelectric generator construction process began with preparing all tools and materials, followed by cutting iron plates that served as the main frame. Cooling fans were installed to regulate the temperature around the Peltier module, which is essential for maximizing heat-to-electricity conversion efficiency. The Peltier module was then combined with supporting components, and iron rods were welded to reinforce the frame construction. A voltmeter and thermometer were installed to monitor the electrical output and temperature during operation. After the assembly was completed, the thermoelectric generator prototype was fully functional and ready for performance testing, as shown in Figure 4.

Prepare tools and materials; Ensure all tools and materials are ready for use; Cut the iron plate; Installing cooling fans; Assembling Peltier components; Welding iron rods; Initial design of the thermoelectric generator; Installing the voltmeter and thermometer; The thermoelectric generator is ready for use

Figure 4. Process of making a thermoelectric generator

The process of making a thermoelectric generator begins with the preparation of tools and materials, including cutting iron plates for the base frame. After that, a cooling fan is installed to maintain a stable temperature in the Peltier module so that the conversion of heat into electrical energy is more efficient. The Peltier module is then assembled with other components, accompanied by welding iron rods to strengthen the construction. Next, a voltmeter and thermometer are installed as instruments to monitor electrical output and temperature. Once all components are in place, the thermoelectric generator is ready to be tested for performance.

However, several technical obstacles were encountered during the implementation stage. For example, the connections between components required high precision to prevent heat leakage, which could reduce the performance of the Peltier module. In addition, the stability of the cooling fan was an important factor because suboptimal cooling could cause overheating, thereby reducing the amount of electricity generated. During the welding stage, there were also challenges in ensuring that the frame remained strong and precise enough to support the module.

In the context of RBL-STEM, these obstacles are actually an important part of the learning process. Students are encouraged to modify designs, evaluate material suitability, and test various alternative technical solutions. Thus, this hands-on experience not only hones technical skills, but also trains critical and creative thinking skills in solving real problems, while strengthening their understanding of biomass-based renewable energy concepts.

Physical, Thermal, and Environmental Evaluation of Cascara Briquettes

To evaluate the quality of cascara briquettes as a renewable energy source, a series of tests were conducted covering physical, thermal, and environmental aspects. The physical and thermal parameters analyzed included moisture content, ash content, gross energy value, density, moisture absorption, burn time, combustion rate, and mechanical strength through a drop test. The test results are presented in Table 1, which shows variations in briquette quality according to differences in the composition of cascara, bletong, and teak leaves. In addition, to assess the environmental suitability of the briquettes, emission tests were also carried out in the form of smoke and odor intensity produced during combustion. The environmental test results are presented in Table 2, which shows that certain formulations are capable of producing briquettes with lower smoke and odor emissions compared to the control and coconut shell comparator.

Table 2. Physical and Thermal Test Results of Cascara Briquettes in Various Formulations

Code	Composition	Moisture content	Ash content	Gross energy	Density	Moisture Absorption	Lighting time	Combustion rate	Drop test
K	100:0:0	76.4	21.7	3396.53	0.905	0	80	0.95	0.90
E1	70:20:0	89.3	23.7	3880.41	0.671	6.25	65	0.88	0.92
E2	60:30:10	88.1	19.5	3816.46	0.625	7.14	70	0.90	0.91
E3	50:40:10	87.5	18.8	3841.67	0.649	6.66	72	0.92	0.93
E4	60:20:20	89	22.5	3753.93	0.591	6.66	68	0.89	0.90
E5	50:30:20	88.7	21.2	3730.34	0.751	0	60	0.85	0.89
E6	40:40:20	87.5	21.3	3649.94	0.613	7.69	75	0.93	0.94
E7	50:20:30	87.5	21.2	3768.21	0.733	5.55	62	0.86	0.90
E8	40:30:30	90.2	25.6	3670.85	0.628	5.26	67	0.91	0.92
E9	30:40:30	79.1	20.2	3275.74	0.753	6.66	78	0.96	0.95
	Coconut shell briquettes	91.6	10.5	5610.69	0.998	3.33	45	0.80	0.96

The composition of cascara, bletong, and teak leaves significantly affects briquette quality parameters, including moisture content, ash content, calorific value, density, moisture absorption, burning time, burning rate, and mechanical strength.

The moisture content of briquettes made from pure cascara (sample K) is relatively lower than that of some of the mixed formulations, although the moisture content of all samples is still quite high (76.4–91.6%). The addition of bletong and teak leaves tended to increase the moisture content (for example, E1 at 89.3% and E8 at 90.2%). This indicates that the mixed materials have fairly strong hygroscopic properties. High moisture content can reduce briquette quality because it causes unstable combustion and requires more energy to evaporate the water before complete combustion occurs. (Pratama et al., 2023), the ideal moisture content for briquettes is below 10%, so these results indicate that the drying process still needs to be optimized. Research by (Aprilliani et al., 2023) also shows that bio-briquettes made from coffee grounds and cascara with a binder produce low moisture content (4.57%), thus meeting briquette quality standards.

Meanwhile, the ash content ranged from 18.8 to 25.6%. The lowest ash content was found in sample E3 (18.8%), while the highest ash content was found in E8 (25.6%). High ash content will reduce combustion quality because more solid residues remain. This is in line with (Maulidian et al., 2022), which states that the higher the ash content, the lower the quality of the solid fuel produced. Similar research by Dewi et al. (2021) reported that high or low ash content will affect the calorific value.

The calorific value (gross energy/GE) of briquettes ranged from 3275.74 to 3880.41 cal/g. The highest calorific value of briquettes was achieved in formulation E1 (70:20:10) at 3880.41 cal/g, which was higher than that of pure cascara (3396.53 cal/g). This shows that adding a moderate proportion of bletong can improve the energy quality of briquettes. Conversely, the lowest calorific value was found in E9 (30:40:30) at 3275.74 cal/g, which was influenced by the excessively low proportion of cascara. These findings show that adding bletong in a proportion of 20–40% can increase the calorific value of briquettes, while an excessive increase in teak leaf composition tends to reduce the energy quality produced. However, the calorific value of all samples was still lower than that of coconut shell briquettes (5610.69 cal/g) used as a comparison.

The density of the briquettes varied, with the highest value found in coconut shell briquettes (0.998 g/cm^3) and pure cascara control (0.905 g/cm^3). High density is associated with briquette compactness, resulting in more stable combustion and longer burning time. Conversely, sample E4 (60:20:20) had the lowest density of 0.591 g/cm^3, indicating that the briquettes were more fragile and produced less than optimal combustion. In this study, tapioca flour adhesive was used in the hope of increasing density. However, the results showed that the use of adhesive in excessive concentrations actually reduced the calorific value. This is in line with the findings of Fansyuri et al. (2023), who stated that the higher the concentration of adhesive used, the lower the calorific value of the briquettes produced.

The moisture absorption test showed values varying between 0–7.69%. Pure cascara briquettes (K) and E5 (50:30:20) had the best moisture resistance with a value of 0%, while the highest value was found in E6 (40:40:20) at 7.69%. High moisture absorption capacity indicates the briquettes' vulnerability to storage conditions. This has the potential to reduce flame quality and mechanical resistance, as the briquettes become more brittle and difficult to burn.

The burning time parameter shows that coconut shell briquettes have the best performance with the fastest burning time (45 seconds), while the cascara–bletong–teak leaf mixture samples range from 60 to 80 seconds. In general, briquettes with high density (such as K and E9) tend to require a longer ignition time because the density of the raw material slows down the entry of oxygen in the initial combustion process. The highest combustion rate was found in E9 (0.96) and the pure cascara control (0.95), indicating that these two briquettes burned faster. Conversely, the lowest combustion rate was found in E5 (0.85), which indicates a longer burning duration. Briquettes with low combustion rates are more desirable because they provide energy efficiency over a longer period of time. The study by (Aprilliani et al., 2023) also reported that the burning rate of coffee grounds biobriquettes was only 2.124 g/minute, indicating a longer and more efficient burning duration.

The drop test results showed that almost all briquettes had a value close to 1, which means they are quite resistant to impact. The highest value was found in E9 (0.96), while the lowest was in coconut shells (0.80). These findings indicate that cascara–bletong–teak leaf mixed briquettes have relatively better mechanical resistance than coconut shell briquettes. Although coconut shell briquettes excel in calorific value, their mechanical strength tends to be lower. Briquettes with high drop test values are generally more resistant to transportation and storage processes.

Overall, the briquette formulations that provided the most optimal results were E1 (70:20:10) and E3 (50:40:10). Both formulations have a combination of high calorific value, relatively low ash content, and stable mechanical properties. However, the calorific value of briquettes is still lower than that of coconut shells, so efforts to improve quality are needed, such as through further carbonization or the addition of more suitable binding agents.

Table 3. Environmental Test Results of Cascara Briquettes in Various Formulations

Sample Code	Composition	Smoke Intensity	Odor	Average	Description
K	100:0:0	3	3	3	Control, moderate smoke and odor
E1	70:20:0	2.5	2.5	2.5	Cleaner than control
E2	60:30:10	2.3	2.4	2.35	Relatively stable
E3	50:40:10	2.8	2.6	2.7	Slightly increased smoke
E4	60:20:20	2.4	2.2	2.3	Lighter odor
E5	50:30:20	2.1	2.0	2.05	Best, low smoke and odor
E6	40:40:20	2.7	2.5	2.6	Smoke tends to be thicker
E7	50:20:30	2.3	2.1	2.2	Almost as good as E5
E8	40:30:30	2.6	2.3	2.45	Small moderate
E9	30:40:30	2.9	2.7	2.8	Most smoke and odor
	Coconut shell briquettes	1.2	1.1	1.15	Almost no smoke and neutral odor

The results of smoke and odor intensity testing showed variations in briquette combustion quality based on differences in raw material composition. Pure cascara briquettes (sample K) produced smoke and odor intensities with an average value of 3, which is categorized as moderate. This condition was used as a comparison to assess the effectiveness of the mixture formulation. The addition of a moderate amount of bletong (samples E1 and E2) reduced smoke and odor intensity. E1 showed an average of 2.5, which was cleaner than the control, while E2 was relatively stable with an average of 2.35. This indicates that bletong plays a role in improving combustion quality by reducing smoke emissions. This finding is in line with Qi et al. (2023), who reported that the use of bio-coal briquettes can reduce brown carbon emissions by 70–81% compared to pure biomass. However, increasing the proportion of bletong to 40% (samples E3 and E6) actually caused the smoke intensity to increase (averaging 2.7 and 2.6, respectively). This phenomenon indicates that too high a proportion of bletong has the potential to produce more concentrated combustion gases. Formulations with a higher proportion of teak leaves showed varying results. Sample E4 (60:20:20) produced a lighter odor (average of 2.3), while E7 (50:20:30) achieved an average of 2.2, which was almost comparable to E5. Sample E5 (50:30:20) was the best formulation with an average of 2.05, showing the lowest smoke and odor intensity among all mixtures. This indicates that a balanced combination of cascara, bletong, and teak leaves can produce cleaner combustion. Studies on briquettes made from local biomass in Indonesia also support these findings, where particle size and density control have been shown to reduce smoke emissions compared to traditional firewood (Hakim et al., 2025). Conversely, samples with a low proportion of cascara and a high proportion of bletong (E9: 30:40:30) showed the worst quality, with an average of 2.8 and characterized by thicker smoke and odor. This confirms that the dominance of bletong in the mixture does not support environmentally friendly combustion quality. In comparison, coconut shell briquettes had an average value of 1.15, with almost no smoke and a neutral odor. These results show that although the calorific value of cascara–bletong–teak leaf mixed briquettes is quite competitive, in terms of smoke and odor emissions, coconut shell briquettes are still the best standard. Overall, the results of this study confirm that variations in raw material composition affect the intensity of briquette smoke and odor. The 50:30:20 (E5) formulation can be recommended as the optimal composition because it produces the lowest smoke and odor emissions, approaching the quality of coconut shell briquettes.

Development of RBL–STEM Learning Tools Based on Cascara Briquette Research

These empirical findings form an important basis for the next stage of research, namely the development of RBL-STEM-based learning tools that integrate the results of cascara briquette testing into the learning experience of students. Thus, the results of briquette optimization are not only technically useful, but also serve as a contextual learning resource that supports the improvement of students' creative thinking skills. The discussion in this study begins with an explanation of the learning tool development process, which was carried out systematically through five stages: analysis, design, development, implementation, and evaluation. Each stage plays an important role in ensuring that the resulting tools meet learning needs. Furthermore, the developed tools are validated by experts and tested for effectiveness in the field, so that the results obtained are not only conceptual but also practical and applicable.

The initial stage of this research is analysis, which includes needs analysis, student analysis, concept analysis, and task analysis. Needs analysis was conducted through a questionnaire, which showed that previous learning tended to be theory-oriented and did not fully provide students with real research experience. This condition resulted in low higher-order thinking skills, particularly creative thinking skills. Therefore, it was necessary to develop Research-Based Learning (RBL) tools with a STEM approach, which could increase student activity, critical thinking, and creativity in the learning process. The results of observations and interviews showed that the majority of students had adequate basic knowledge of renewable energy and biomass concepts. However, their skills in conducting experiments, processing data, and designing technical solutions are still limited. In addition, students showed a high interest in hands-on practices that integrate theory with real-world applications, such as the manufacture of cascara briquettes and their use in thermoelectric generators. These findings form an important basis for designing learning tools that are tailored to the characteristics and needs of students. Concept analysis was conducted to systematically identify and detail the main concepts to be conveyed, which included renewable energy (particularly coffee cascara biomass), the briquette manufacturing process (material composition, physical, thermal, and energy properties), and the working principles of thermoelectric generators (conversion of heat energy into electrical energy through Peltier modules). This analysis aims to ensure that the material presented is relevant, up-to-date, and supports the achievement of learning objectives, while integrating elements of science, technology, engineering, and mathematics. Task analysis results in task designs that actively involve students in the scientific inquiry cycle. These tasks include formulating briquette materials with variations in the composition of cascara, bletong, and teak leaves; physical, thermal, energy, and emission testing of briquettes; designing and testing a simple thermoelectric generator fueled by cascara briquettes; and presenting research results through reports and group presentations. This task analysis aims to ensure that students are directly involved in problem formulation, experimentation, data analysis, and solution development.

The second stage, namely design, aims to develop an RBL-based learning device prototype with a STEM approach after the learning objectives have been set. At this stage, descriptive tests were developed to measure students' creative thinking skills, media such as learning videos, journal articles, and presentation materials were selected, and learning formats and strategies that integrated discussion, experimentation, and presentation were determined. All tools were then validated by experts to ensure the suitability and validity of the instruments, so that they were ready for use in the implementation stage. One of the tools developed is the Student Worksheet (LKM), which is designed following the STEM-based Research-Based Learning model to support creative thinking skills, facilitate understanding of the cascara briquette concept, and provide space for students to record ideas and solve problems independently. Figure 1 shows an example of the LKM developed.

Figure 5. Student Worksheets developed by researchers

The third stage, namely product prototype development, begins with the formulation of objectives, identification of necessary activities, and design of the learning process. Once the LKM has been developed, the next stage is validation. Media experts assess design aspects, including attractive yet proportional variations, color selection, balance between text and images, visual harmony with content and tasks, creativity, appeal, layout consistency, ease of use, and the media's ability to support independent and active learning. Content experts assess the accuracy and quality of the content, the depth and scope of the material, the appropriateness of the language, the inclusion of lesson plan titles, the clarity of objectives, the accuracy and conciseness of the language, and the relevance of the learning components. The validation results from both experts are presented in the following Table 4 and Table 5.

Table 4. Validation Results by Validators

Validator	Average Percentage (%)	Category
Subject Matter	92	Highly Valid
Media Expert	81	Valid

Advice from media expert validators can be seen in the Figure 6.

Figure 6. Advice from media expert validators

The design is still simple, and the layout is not very proportional. The color selection tends to be monotonous, making it less appealing. The text appears dense, and there is no comfortable spacing or typography. Illustrations or supporting images are still limited, giving a somewhat “empty” visual impression. Navigation and page division are not consistent. Results of revisions by media expert validators can be seen in the Figure 7.

Figure 7. Results of revisions by media expert validators

The design is neater, with a balanced layout of text and images. The colors are more contrasting and harmonious, enhancing visual appeal. The text is more concise, the typography is clear, and the use of spacing makes it easy to read. There are more relevant images/illustrations, reinforcing understanding of the material. Page navigation is more consistent, giving a professional and systematic impression.

After revising and compiling Draft 2 of the LKM, the next step was to test students to evaluate their responses to the teaching materials. Students' answers were converted into percentage scores and categorized based on feasibility. The assessment covered three aspects: material feasibility, presentation feasibility, and language feasibility, as shown in Table 5.

Table 5. Student Response Results

No	Component	Percentage (%)	Category
1	Content suitability	88	Highly suitable
2	Presentation suitability	82	Highly suitable
3	Language suitability	85	Highly suitable
Average		85	Highly suitable

The test results showed an average total of 85%, which is considered very good, so that LKM is deemed suitable for use in learning.

Table 6. Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest	53.5453	35	6.01686	1.01703
	Postest	62.5971	35	8.89463	1.50347

Table 7. Paired Sample Correlations

		N	Correlation	Sig.
Pair 1	Pretest & Postest	35	.928	.000

Table 8. Paired Sample Test

		Paired Differences					t	df	Sig.(2-tailed)
					95% Confidence interval of the difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pretest-Postest	-9.14	3.99	.67	-10.51	-7.77	-13.5	34	.000

The results of the analysis show an increase in students' creative thinking skills after the implementation of Research-Based Learning (RBL) with a STEM approach using cascara briquettes and thermoelectric generators. The mean pretest score was 53.54, while the mean posttest score increased to 62.60. This shows an increase in the mean score of 9.14 points. The correlation test between the pretest and posttest produced a value of $r = 0.928$ with a significance of $p = 0.000 < 0.05$, which means that there is a very strong and significant relationship between the pretest and posttest results. This means that students who have high initial abilities tend to continue to perform well after treatment, even with significant improvements. The difference test using the Paired Sample T-Test obtained a value of $t = -13.539$, with $df = 34$, and a significance value of $p = 0.000$ ($p < 0.05$). This indicates that there is a significant difference between the pretest and posttest scores. The 95% confidence interval also shows a range of (-10.51 to -7.77), which does not include zero, reinforcing the conclusion that the difference is not coincidental. Thus, it can be concluded that research-based learning with a STEM approach through a project to optimize cascara briquettes as a heat source for thermoelectric generators is effective in improving students' creative thinking skills. This is in line with research Pratiwi et al. (2025) which states that research-based learning is able to encourage students to find new ideas through the inquiry process, thus having a positive impact on creative thinking skills. This improvement includes aspects of fluency, flexibility, originality, and elaboration. These findings are consistent with the results of research Khalil et al. (2023) which reports that the project-based STEM approach provides more space for students to explore, test, and modify solutions, thereby significantly improving creative thinking skills compared to conventional learning. In this context, the application of the RBL-STEM model in renewable energy research not only impacts cognitive mastery but also trains students to face real challenges through creativity and innovation. The results of this study are reinforced by the findings of Sanjayanti et al. (2025), which show that the integration of research-based learning with the STEM approach has proven to be an effective learning strategy in improving the research skills of biology students, while also equipping them with applicable and research-oriented scientific abilities.

Conclusion

This study shows that variations in the composition of cascara, bletong, and Tectona grandis leaves have a significant effect on the quality of the biomass briquettes produced. Formulation E1 (70:20:10) produced the best thermal performance with the highest calorific value of 3880.41 cal/g, relatively low ash content, and good mechanical stability. Meanwhile, formulation E5 (50:30:20) showed the most superior environmental performance with the lowest smoke and odor intensity (average of 2.05), good moisture resistance, and a more efficient burning rate. These findings confirm that cascara has the potential to be developed as a sustainable biomass energy source, although the calorific value of the mixed briquettes is still below the standard for coconut shell briquettes, requiring further optimization of the carbonization process, adhesive type, and production techniques. The implementation of RBL-STEM learning through the cascara briquette–thermoelectric generator project proved effective in improving students' creative thinking skills, as indicated by an average score increase of 9.14 points and a significant Paired Sample T-Test result ($t = -13.539$; $p = 0.000$). The improvement covered aspects of idea fluency, flexibility, originality, and elaboration, confirming the effectiveness of integrating authentic research in strengthening higher-order thinking skills. However, this study has limitations, including the high moisture content of the briquettes due to the suboptimal drying process and the limited scope of material characterization. Further research is recommended to implement a more controlled carbonization system, explore alternative adhesives and densification techniques, and expand testing in an educational context with more diverse samples. Overall, the findings of this study contribute to the development of plantation waste-based biomass energy and a relevant RBL-STEM learning model to strengthen 21st-century competencies.

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Author Contributions

Conceptualization, N.K and N.C.P; methodology, formal analysis, data curation, and writing—preparation of the original draft, N.K; investigation, N.C.P; resources, writing—review and editing, and validation, N.K and N.C.P; Visualization, N.C.P. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The author declares that there is no conflict of interest.

References

Agatha, A. B., Dafik, & Kristiana, A. I. (2025). Development of RBL-STEM Learning to Improve Students' Conjecturing Thinking Skills in Asymmetric Cryptography Problems in Blockchain Technology Using Super (a,d)-Hyperedge Antimagic Total Labeling of Hypergraphs. *World Journal of Advanced Research and Reviews*, *25*(1), 1754–1763. https://doi.org/10.30574/wjarr.2025.25.1.0206

Anggono, W., Gotama, G. J., Pronk, C., Hernando, I. C., & Sutrisno, T. (2023). Characteristics of biomass briquettes from coffee husk as sustainable fuel. *BIO Web of Conferences*, *62*. https://doi.org/10.1051/bioconf/20236203002

Aprilliani, F., Triastuti, D., & Suciati, F. (2023). Pengaruh Komposisi Ampas Kopi dan Cascara Terhadap Karakteristik Biobriket. *Agroteknika*, *6*(2), 289–299. https://doi.org/10.55043/agroteknika.v6i2.232

Aridi, R., Faraj, J., Ali, S., Lemenand, T., & Khaled, M. (2021). Thermoelectric Power Generators: State-of-the-Art, Heat Recovery Method, and Challenges. *Electricity*, *2*(3), 359–386. https://doi.org/10.3390/electricity2030022

Cruz, I. A., Santos Andrade, L. R., Bharagava, R. N., Nadda, A. K., Bilal, M., Figueiredo, R. T., & Romanholo Ferreira, L. F. (2021). Valorization of cassava residues for biogas production in Brazil based on the circular economy: An updated and comprehensive review. *Cleaner Engineering and Technology*, *4*(June), 100196. https://doi.org/10.1016/j.clet.2021.100196

Dewi, R. P., Saputra, T. J., & Widodo, S. (2021). Studi Potensi Limbah Kulit Kopi Sebagai Sumber Energi Terbarukan Di Wilayah Jawa Tengah. *Journal of Mechanical Engineering*, *5*(1). https://doi.org/10.31002/jom.v5i1.3946

Dione, N. C., Lestari, P., Susanti, D. Y., Masithoh, R. E., Azzahra, R. L., Chairani, A. M., & Rohma, A. S. D. (2025). Cellulose Extraction from Robusta Coffee Husk (Coffea canephora) as Alternative Material from Sustainable Agricultural Waste Utilization. *IOP Conference Series: Earth and Environmental Science*, *1438*(1). https://doi.org/10.1088/1755-1315/1438/1/012073

Erdiyanto, A. S., Asshidiqi, M. H., & Syachrir, G. (2024). Bio-Briquettes Production from Spent Coffee Grounds, Composite Organic Waste, and Coconut Shells by Using Carbonization. *IOP Conference Series: Earth and Environmental Science*, *1395*(1). https://doi.org/10.1088/1755-1315/1395/1/012010

Fansyuri, M., Nurkholis, -, Mikhratunnisa, -, Rizaldi, L. H., & Ariskanopitasari, -. (2023). Karakteristik briket ampas tebu (bagasse) dari bahan perekat tepung beras ketan. *Jurnal Agrotek Ummat*, *10*(1), 1. https://doi.org/10.31764/jau.v10i1.12266

Fitriyano, G., Ismiyati, I., Purnawan, I., & Ramadhan, R. F. (2023). Production and Characterization of Bio-Briquettes from Coconut Leaves and Cassava Peels. *International Journal of Applied Sciences and Smart Technologies*, *5*(2), 1–12. https://doi.org/10.24071/ijasst.v5i2.5567

Gibran, M. A., Novianto, S., Supriyadi, S., & Bhikuning, A. (2024). Termoelektrik Generator Dan

Fungsinya. *Jurnal Penelitian Dan Karya Ilmiah Lembaga Penelitian Universitas Trisakti*, *9*, 404–418. https://doi.org/10.25105/pdk.v9i2.20109

Gita, R. S. D., Waluyo, J., Dafik, & Indrawati. (2023). The Analysis of the Implementation of RBL-STEM in Improving Students Creative Thinking Skills in Solving the Use of Chitosan as an Antibacterial for Processed Meat. *European Journal of Education and Pedagogy*, *4*(2), 36–47. https://doi.org/10.24018/ejedu.2023.4.2.524

Hakim, L., Iswanto, A. H., Lubis, Y. S., Wirawan, A. J., Batubara, R., Kim, N. H., Antov, P., Rogoziński, T., Hua, L. S., Chen, L. W., Selvasembian, R., Jayusman, & Sutiawan, J. (2025). Charcoal Briquette Manufactured from Indonesian Sugar Palm Bunches (Arenga longipes Mogea) as Biomass-Based New Renewable Energy. *Journal of Renewable Materials*, *13*(3), 639–652. https://doi.org/10.32604/jrm.2025.056365

Jouhara, H., Żabnieńska-Góra, A., Khordehgah, N., Doraghi, Q., Ahmad, L., Norman, L., Axcell, B., Wrobel, L., & Dai, S. (2021). Thermoelectric generator (TEG) technologies and applications. *International Journal of Thermofluids*, *9*. https://doi.org/10.1016/j.ijft.2021.100063

Joy, L. M., Henrich N, G. Y., Nimfa A, J. N., Mae B, P., & Louis G, L. B. (2024). From Waste to Sustainable Energy: Harnessing Organic By-Products in Developing Eco-Briquettes. *International Journal of Advanced Multidisciplinary Research and Studies*, *4*(6), 977–980. https://doi.org/10.62225/2583049x.2024.4.6.3539

Junior, O. H. A., Silva, E. A. da, Lira, E. R. de, Degiorgi, S. V. B., & Carmo, J. P. P. do. (2024). Comparative Analysis and Integrated Methodology for the Electrical Design and Performance Evaluation of Thermoelectric Generators (TEGs) in Energy Harvesting Applications. *Energies*, *17*(20). https://doi.org/10.3390/en17205176

Khalil, R. Y., Tairab, H., Qablan, A., Alarabi, K., & Mansour, Y. (2023). STEM-Based Curriculum and Creative Thinking in High School Students. *Education Sciences*, *13*(12). https://doi.org/10.3390/educsci13121195

Komaria, N., Suratno, Prihatin, J., & Sudarti. (2020). An analysis of innovation on the utilization of cascara by coffee farmers. *Journal of Physics: Conference Series*, *1563*(1). https://doi.org/10.1088/1742-6596/1563/1/012015

Lubwama, M., Yiga, V. A., Muhairwe, F., & Kihedu, J. (2020). Physical and combustion properties of agricultural residue bio-char bio-composite briquettes as sustainable domestic energy sources. *Renewable Energy*, *148*, 1002–1016. https://doi.org/10.1016/j.renene.2019.10.085

Maulidian, O., Wahyuni, P. N., Pujiastuti, C., Widodo, L. U., & Edahwati, L. (2022). Kajian Peningkatan Nilai Kalor Briket Blotong Dengan Penambahan Pelepah Pisang Dan Molase. *Jurnal Teknik Kimia*, *16*(2), 101–106. https://doi.org/10.33005/jurnal_tekkim.v16i2.3052

Mustafa, S., & Ibrahim, S. (2023). Thermal and Physical Properties of Briquette Fuels from Coconut Shells and Cocoa Shells. *Bioresources and Environment*, *1*(3), 45–53. https://doi.org/10.24191/bioenv.v1i3.39

Patil, G. (2019). The possibility study of briquetting agricultural wastes for alternative energy. *Indonesian Journal of Forestry Research*, *6*(2), 133–139. https://doi.org/10.20886/IJFR.2019.6.2.133-139

Pratama, A. T., Nuryanto, A., Setiadi, B. R., Rosyadi, S., Limiansi, K., & Kusumawardani, N. (2023). Alternative fuels from recycling dried leaves of Tectona grandis into briquettes. *AIP Conference Proceedings*, *2671*(March). https://doi.org/10.1063/5.0116493

Pratiwi, A. F. R., & Rosdiana, L. (2025). Implementasi Inkuiri Terbimbing Melalui Pendekatan Stem Untuk Meningkatkan Keterampilan Berpikir Kritis. *BIOCHEPHY: Journal of Science Education*, *5*(1), 71–77. https://doi.org/10.52562/biochephy.v5i1.1439

Qi, J., & Wu, J. (2023). Effects of Bio-Coal Briquette for Residential Combustion on Brown Carbon Emission Reduction. *Processes*, *11*(6). https://doi.org/10.3390/pr11061834

Rashif, M. N., Hartini, S., Sari, D. P., Ramadan, B. S., Matsumoto, T., & Balasbaneh, A. T. (2025). Life cycle assessment of biomass waste briquettes as renewable energy. *Global Journal of Environmental Science and Management*, *11*(1), 207–224. https://doi.org/10.22034/gjesm.2025.01.13

Ritli, A. El, & Adlini, M. N. (2022). The effect of guided inquiry learning model on students' critical thinking skills in biology learning. *BIO-INOVED : Jurnal Biologi-Inovasi Pendidikan*, *4*(3), 241. https://doi.org/10.20527/bino.v4i3.13841

Saba, S., El Bachawati, M., & Malek, M. (2020). Cradle to grave Life Cycle Assessment of Lebanese biomass briquettes. *Journal of Cleaner Production*, *253*, 119851. https://doi.org/10.1016/j.jclepro.2019.119851

Sanjayanti, A., Alamsyah, M., & Fadhillah, M. (2025). Implementasi Research-Based Learning Untuk Mengoptimalkan Research Skills Mahasiswa. *Jurnal Penelitian Nusantara*, *1*, 500–508. https://doi.org/10.59435/menulis.v1i8.616

Susanto, Kristiana, A. I., Dafik, Fatahillah, A., Venkatachalam, M., & Tanna, D. (2025). Enhancing

Students' Conjecturing Skills Through RBL-STEM with Antimagic Coloring and Geometric Transformation in Batik Design. *Emerging Science Journal*, *9*(2), 868–889. https://doi.org/10.28991/ESJ-2025-09-02-019

Tesfaye, A., Workie, F., & Kumar, V. S. (2022). Production and Characterization of Coffee Husk Fuel Briquettes as an Alternative Energy Source. *Advances in Materials Science and Engineering*, *2022*. https://doi.org/10.1155/2022/9139766

US EIA. (2025). *Monthly Energy Review*. Retrieved from www.eia.gov/mer

Van Toan, N., Kim Tuoi, T. T., & Ono, T. (2022). High-performance flexible thermoelectric generator for self-powered wireless BLE sensing systems. *Journal of Power Sources*, *536*. https://doi.org/10.1016/j.jpowsour.2022.231504

Wulandari, Y. N., Kristiana, A. I., & Dafik. (2025). The development of RBL-STEM learning tools to improve students' computational thinking skills in solving plant disease classification problems using convolutional neural network segmentation. *World Journal of Advanced Research and Reviews*, *25*(1), 804–812. https://doi.org/10.30574/wjarr.2025.25.1.0086