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Forcing Sustainable Coconut Charcoal Briquette Production with Clean Energy for Indonesia's ENDC 2030

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Abstract: Indonesia through its Enhanced Nationally Determined Contribution (ENDC), targets a 31.89% reduction in greenhouse gas (GHG) emissions with national efforts and 43.20% with international assistance by 2030. The purpose of this study is to develop quality control of materials and evaluate the optimation of using carbon waste in coconut charcoal briquette production. The laboratory test method by CHNS provides the quantitative data of carbon emission high risk in coconut shell charcoal raw, semi-finished materials, and finished briquette. The method of analytical hierarchy process (AHP) is used to find that penta-helix collaboration scheme between between government, industries, institutions, societies, and consumers has the AHP highest priority with score 0.71. The combination of reutilizing energy based on a reject briquette oven has been proven to reduce emissions into make carbon neutral. Export-standard shisha briquettes based on CHNS has the highest carbon concentration (77.57%) and the second highest is oven fuel powder/reject briquette material (59.87%), means the briquettes have a maximum combustion rate and minimal ash release into the air. This work builds a regulation concept of agro-industry sector in the practice of material quality control for clean, low-carbon production.

Keywords: Analytical hierarchy process; Carbon emission; Clean production; Coconut charcoal briquette; Greenhouse gas

Introduction

The development of agro-industry has the potential to become the largest national producer of production waste, posing a threat to the degradation of soil, water, and environmental quality (Koohafkan et al., 2012). Based on the 2022 IPCC data report, it was revealed that agro-industrial activities have contributed at least 42% of global carbon emissions (Viglione et al., 2022). The problem of agro-industrial waste and pollution threatens environmental stability, making carbon emission mitigation in the agro-industrial sector central to supporting the exclusivity of low-carbon production systems. The 2022 World Meteorological Organization (WMO) report revealed that there is a possibility of a global temperature increase of up to 1.5°C - 2.0°C in the next five years (World Meteorological Organization, 2023).

This research has 2 objectives to develop quality control of coconut shell charcoal materials and evaluate the optimation of using carbon waste for supporting carbon neutral production. Analyzing the quality standard of coconut shell charcoal raw materials make a solution to decreasing malproduction impact to the high carbon emission and develop storage method in warehouse (Sudarto et al., 2017). The evaluation of using carbon waste for supporting carbon neutral production is needed for emerging energy waste and inefficiency production process.

Coconut shell charcoal storage determines the quality of the briquettes produced. Storage in the warehouse typically lasts for one week to one month, depending on consumer demand for briquettes. Unfortunately, storage quality in the warehouse is still inadequate, such as high humidity levels and increased temperatures in the charcoal material, as it is a fuel.

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Exposure to humid air will reduce the optimal function of the lignin charcoal and cause the final dry briquettes to become musty (Yildirim & Candan, 2022). Consequently, briquette quality declines and rejects accumulate (Junita, 2025).

Furthermore, damaged material can increase the potential for carbon emissions due to excess waste, and the amount of rejects used for oven combustion energy becomes unbalanced with the output of export-standard briquettes according to market demand. For incresing clean and sustainable production, untilizing briquette reject as carbon waste and keep material storage in controled condition (Li et al., 2023). Therefore, good air circulation is needed by installing several turbine ventilators on the roof of the storage warehouse to control humidity and maintain a more stable room temperature (Jiang et al., 2025).

The targeted outputs of this research are the implementation of low-carbon production systems is expected to increase agroindustrial efficiency and support climate change mitigation. These results are important for strengthening the policy direction of carbon trading targets with penta-helix collaboration (Mccullagh et al., 2024). Penta-helix collaboration was initiated by the government as a whole and socialized to companies and the community regarding the target program for optimizing the use of production waste as production materials and the target for low-emission lifestyles (Khasanah & Asih, 2026). The penta-helix collaboration scheme strengthens the direction of consistent carbon trading target policies between governments, companies, institutions, communities, and consumers (Situmorang et al., 2025).

This work is important to analyze clean energy from efficiency and circular production system perspective. Indeed, clean production practices using renewable energy to achieve carbon neutrality require a thorough review, including the cost of production materials which are often substantial. However, the impact of environmental externalities is equally important to consider as production efficiency and the cost of carbon emission tax amnesty when conducting carbon offsets through carbon neutral efforts in the utilization of briquette production waste for production energy and increased control of production materials (Akash et al., 2024). The novelty of this research focuses on clean and sustainable production strategies with low-emission materials and maximum use of residual energy in the agro-industry. The scope of the research novelty is only on the concept of regulations that can be applied to the agro-industry sector in the practice of material quality control for clean, low-carbon production. However, this research still has limitations, studies on carbon offset and carbon trading strategies will not be discussed in this research and will be the development of future research.

Method

Laboratory Test

These results are important to strengthen the policy direction of carbon trading targets with pentahelix collaboration. The first method use laboratory materials test that uses Carbon (C), Hydrogen (H), Nitrogen (N), Sulfur (S), Calor/Energy and Moisture. Carbon (C), Hydrogen (H), Nitrogen (N), Sulfur (S) material test were indicator to observe quality control material and carbon emission potential during drying process. The high carbon and sulfur in raw materials in the warehouse detect low quality material cause of the storage factor. Calor/Energy material test is used to identify the lignin content to produce high carbon to measure the optimal heat output of briquette combustion. Ash material test refers to the observation of heat capability and residue from raw, semi-finished materials, and finished briquette. Moisture material test needs to observe the quality of material and the impact of storage warehouse to the moisture of charcoal.

Analytical Hierarchy Process (AHP)

AHP procedure was taken by expert interviews. The AHP analysis interviewed for 6 experts and experienced people in greenhouse gas (GHG), carbon trading, and carbon emission (Table 2). The interview data of experts present about a scheme of carbon trading and clean production low emission. The result of interview shows penta-helix collaboration and develop the implementation of measurement, reporting and verification (MRV).

Table 1. The Data Adequacy of Analytical Hierarchy Process (AHP)

Aspect	Result
Number of expert respondents	6 people
Sampling method	Snowball Sampling
Level of homogeneity (average CV)	0.21 (quite consistent)
Sufficiency category	Quite representative for exploratory AHP

Analytical hierarchy process (AHP) analyzes carbon decreasing and green circular production in agroindustry to make alternative solution based on expert judgement (Mukti et al., 2025). AHP breaks the complex problem into a hierarchy that starts with the main goal (designing an effective and clean production with low carbon emission). This is followed by criteria and sub-criteria (production process in low emission and actors collaboration), and the policy alternatives or specific barriers to be evaluated (Dunn, 2018).

Briquette production leaves a carbon footprint, particularly in the oven drying process, which requires significant energy from the entire process. Suboptimal combustion rates in rejected briquettes, whose quality decreases due to inadequate storage of semi-finished materials, can potentially lead to negative environmental impacts and production inefficiencies (Hanafiyah et al., 2024). In other words, briquette material storage techniques and the use of clean and circular energy are important factors in reducing carbon emissions and environmental degradation (Hasanuzzaman, 2020). Recycling schemes for rejected briquettes and the implementation of turbine ventilators are goals in achieving the Sustainable Development Goals (SDGs) regarding clean and affordable energy and resonable consumption and production (Vayed & Purnomo, 2022).

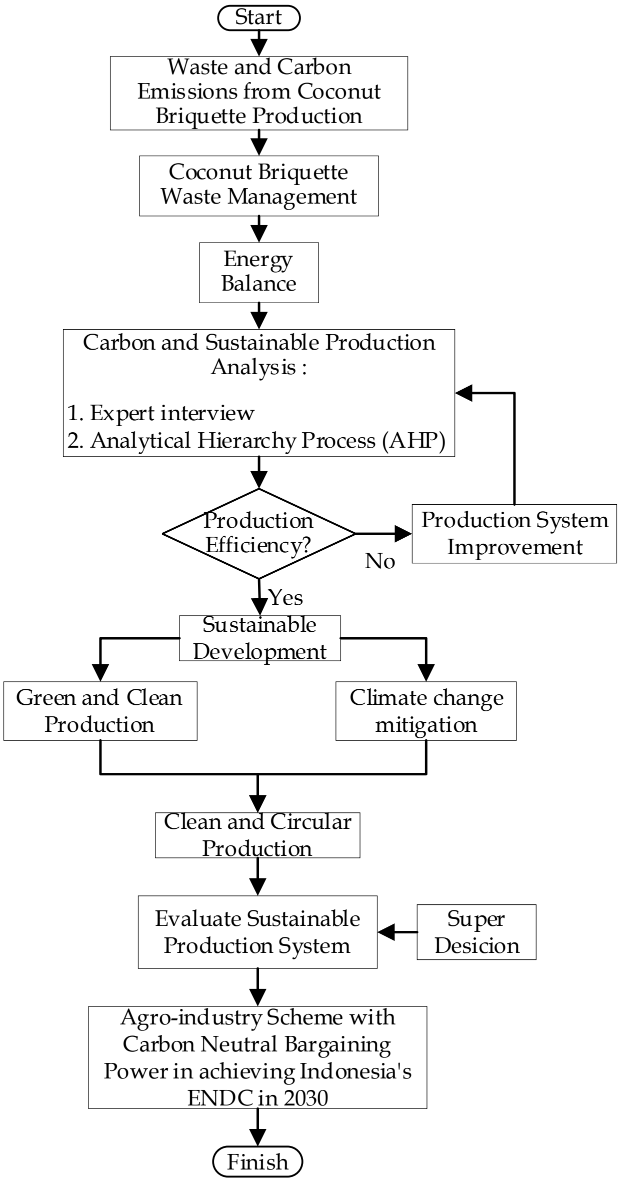

Figure 1. Flowchart of research method

This study designs a proposal based on analysis of CHNS tests, ash content, heat/energy, and moisture content, as well as expert interviews using the analysis hierarchy process (AHP) method, with the aim of providing alternatives (Widya et al., 2026). The analysis aims to determine the impact of material quality as influenced by storage factors and carbon reduction strategies for efficiency and clean production (Jawjit et al., 2024). The findings of this study can form the basis for the value of agro-industry bargaining power on carbon offset potential and can be developed for voluntary carbon market policy strategies in future research (MacKerron et al., 2009).

Result and Discussion

Result

Laboratory results indicate sustainability management in the briquette production and low emission process. The CHNS test results below show that export-standard shisha briquettes have the highest carbon concentration (77.57%) and the second highest for oven fuel powder/reject briquette material (59.87%) (Table 2). This means the briquettes have a maximum combustion rate and minimal ash release into the air. Although the environmental impact and carbon emissions of rejected briquettes are quite high, maximizing the use of rejected briquettes as an alternative energy source in the oven drying process and controlling the number of rejected briquettes can be a bargaining chip in implementing carbon neutrality.

Table 2. Total Average of CHNS

Sample	Ash (%)	Calor/Energy (cal/g)	Moisture (%)
Recycled Briquettes	2.29	6867	7.12
Fuel Smell Briquettes	20.49	4533.52	7.33
Export Standard Shisha Briquettes	22.13	4283	3.84
Fuel Powder	1.29	6026	21.98
Fuel Ash (Wet)	5.09	3781	37.45
Screened Ash for Shisha Briquettes	19.63	2987.51	37.60

The storage briquette material in the warehouse is a part of crucial process that determines quality of product. The reject briquette products may use for the alternative energy in the drying oven process, thus implementing circular and carbon-neutral production. So, his initiative can be transformed into a valuable resource by converting waste and production emissions into a circular energy source.

Table 3. Total Average of Calor/Energy, and Moisture Test for Coconut Briquette Materials (Source: Processing Data, 2025)

Sample	C (%)	H (%)	N (%)	S (%)
Recycled Briquettes	55.06	4.05	1.46	0.18
Odor Fuel Briquettes	49.17	3.85	1.69	0.24
Export Standard Shisha Briquettes	77.57	3.38	1	0.13
Fuel Powder	59.87	4.49	1.21	0.15
Fuel Ash (Wet)	13.71	1.18	0.48	0.07
Screened Ash for Briquettes	15	0.9	0.41	0.07

Storage conditions for raw and semi-finished materials in warehouse with poorly controlled temperature and environmental conditions affect production quality (Singh et al., 2023). Coconut briquettes, made from this type of fuel material, are significantly affected by changes in humidity and room temperature (Mgeni et al., 2024). The lignin in coconut charcoal, which generates heat and absorbs carbon for maximum combustion can decrease if humidity is high and the material temperature absorbs too much heat from the surrounding air (Karthikeyan et al., 2024). The room conditions shown in (Figure 2) below appear very humid due to the high rainfall in the factory area, coupled with the open space and the warehouse roof, which appears to lack upward airflow (Wan & Liu, 2022). Unventilated upward airflow will bounce back and be absorbed into the material (Marczak et al., 2022).

Figure 2. The condition of material warehouse (Source: Processing Data, 2025)

On the other hand, poor quality control in material warehouses results in a high risk of mass production failure, leading to a buildup of defective briquettes. This can lead to increased emissions during the production process, as rejected briquettes have lower heating power and produce higher levels of smoke. Therefore, using a turbine ventilator on the warehouse roof, designed to draw out hot and humid air, can significantly reduce the risk of charcoal material quality degradation and improve stable room temperature control (Suryadi et al., 2019).

Figure 3. Turbin Ventilator in The Warehouse Rooftop (Source: hbjinbang.en.made-in-china.com, 2022)

Consistency Ratio (CR) and Sensitivity Analysis

The Consistency ratio (CR) of hierarcy analysis shows stability scores between 6 respondents about carbon trading strategy in an effort to reduce emissions by the agro-industry. Valid score of CR is under 0.1 (10%) and this CR has strong valid score in -0.0022 (Table 3). Consistency Index (CI) has good score with -0.0020 that means stability of responders. While the highest eigen score is 3.99 as the valid sensitivity and consistency alternative strategy to build scientific carbon market scheme.

Here are the results of expert correspondents. Dr. Haskarlianus Pasang as Head of Operations Sustainability, Sinarmas Agribusiness and Food said carbon trading awareness is necessary across all industrial sectors, public awareness of maintaining a low-carbon lifestyle has a significant impact. The environmental impact of everyday activities, such as the use of fossil fuel-powered vehicles and wasteful household electricity consumption, also contributes significantly to carbon emissions. Therefore, the government needs to initiate the dissemination of carbon reduction missions and carbon trading schemes such as the carbon tax amnesty to promote sustainable and integrated low-carbon lifestyles. This requires a pentahelix collaboration between the government, briquette and agro-industry entrepreneurs, carbon trading institutions, the community, institutions, and the public.

Johanis R. Pangala, M.Si as Yapeberi Foundation Researcher said the Enhanced Nationally Determined Contribution (ENDC) has raised Indonesia's national carbon reduction target to 2030. Implementing this approach in just one coconut briquette company is insufficient, as the impact of the changes will likely be minimal. At the very least, the concept of utilizing production waste as fuel can be implemented nationally.

Ni Putu Ayu Eka Sundari, SP. MSc.Agr as Researcher at Waste Management and Community Development, WRI Indonesia said developing a coconut shell briquette production system is crucial to the strategy for reducing greenhouse gas (GHG) emissions. Reusing coconut shell briquette waste is an alternative, but it requires clear emission calculations. We can determine whether the external impacts of the production process are efficient and low emissions by looking at the amount of carbon released into the air, the efficiency of the method, and its environmental impact.

Socialization of lifestyle and carbon emission reduction targets between the government, the public, businesses, and carbon certification services plays a crucial role in achieving emission reductions by 2030. Coconut briquette production by reusing rejected briquette waste supports maximum optimization of the briquette production system. Emission reductions need to be ensured. However, production efficiency with maximum system utilization is a consideration to reduce environmental impact (Janjuhah et al., 2021). The government's dissemination of carbon emission reduction targets businesses and the public needs to be the strongest proposal, along with penta-helix collaboration that strengthens target implementation for every businessperson and individual.

Wahyudi Ali Adam as Capital Market Supervisory Expert, OJK said pentahelix collaboration can be a crucial anchor for the government in building an integrated system and a more stable Indonesian carbon market. Currently, the Indonesian carbon market is far from stable like the stock market. The plan is for the OJK to directly monitor the Indonesian carbon market and ensure its stability, like the current stock market.

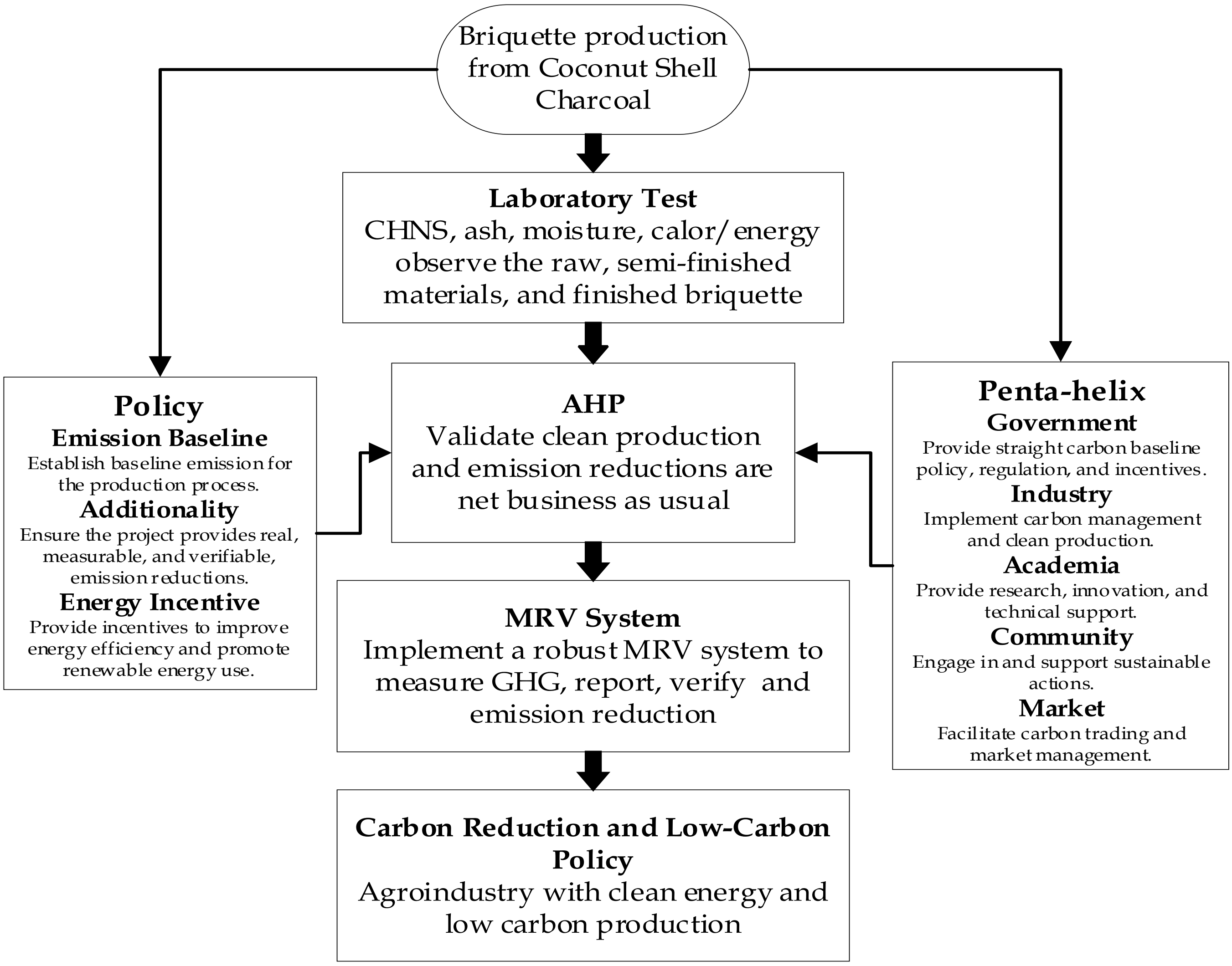

Figure 4. Flowchart of AHP strategy

Akhmad Fatikhudin, S.T., an assistant at the IPB University Agro-Industrial Engineering Laboratory, stated that pentahelix collaboration and the socialization of the impact of carbon trading can be pillars of sustainable national circular economic growth. The government needs to further educate the public about the importance of collaboration in reducing carbon emissions in everyday life. Expert stakeholders provide pairwise comparisons, judging which criterion or alternative is more important and by how much. The analysis uses fixed numerical scale and qualitative factors that are normally hard to measure. The resulting weights allow researchers or policymakers to rank barriers (such as concern over loss of sustained revenue, lack of company capabilities, additional costs, bureaucratic complexity, low transparency, or limited trading volume in IDXCarbon) and to see which ones have the greatest negative impact on participation in carbon trading.

Agus P. Sari as CEO of Landscape Indonesia shares his field experience that the effectiveness of carbon emission reduction strategies in biomass-based industries such as coconut shell briquettes is also determined by the strength of institutional arrangements and a supportive policy framework. Penta-helix collaboration involving government, industry, academia, communities, and market or financing actors is a key factor in increasing connectivity, awareness, and the effectiveness of carbon emission reduction programs. Voluntary carbon markets are increasingly relevant under the pressure of the additionality principle which requires that the resulting emission reductions significantly exceed business-as-usual conditions (PWC Indonesia, 2024).

The main recommendation for alternative cleaner production system policies from expert respondents refers to increasing penta-helix collaboration and public outreach. Implementing low-emission energy use in daily life requires collaboration from all levels of the region. This collaboration includes government, industries, institution, communities, and consumers in an effort to support sustainable emission reduction programs.

Table 4. Pairwise Matrix

Parameter	Score Result	Stability
λmax	3.99	Risk
CI	-0.0020 (consistent)	Stable
CR	-0.0022 (Valid)	Stable

Eigenvalue

The criterias of analytical hierarcy process (AHP) indicate four main priorities of alternative strategy to create carbon trading policy scheme. High value of eigen vector is the penta-helix collaboration strategy in 0.27 with the second alternative in community empowerment in 0.26. Measurement, reporting, and verification (MRV) implentation as baseline technology in reusing carbon emission to convert carbon offset in voluntary market has third alternative position with score 0.26. Additionality concept of carbon offset certification provides validity to strength carbon neutral. Pyrolisis and Co-firing Development have minimum eigen vector score in 0.21 as the last alternative strategy.

Table 5. Eigen Vector Analysis

Criteria	Eigen Vector
Penta-helix Collaboration	0.28
Community Empowerment	0.26
MRV	0.26
Pyrolisis and Co-firing Development	0.21

Table 6. Penta-helix Collaboration Mapping

Penta-helix	Needs
Government	a. Monitoring carbon reduction target policies through integrated penta-helix collaboration. b. Review of carbon trading policy recommendations from low-carbon briquette production systems. c. Regulation of the Minister of Environment and Forestry Number 13 of 2023 and Law Number 16 of 2016 are the basis for implementing carbon trading policies in Indonesia.
Carbon Trading Service	a. Penta-helix collaboration is needed to increase connectivity and awareness of carbon reduction. b. Voluntary carbon markets with the concept of "additionality" and carbon reduction targets through government support.
Briquette Industries	a. High-quality and low-carbon briquette products at affordable prices. b. Circular utilization of carbon biomass for briquette production. c. Efficient and economical production systems through the implementation of carbon product trading.
Consumers	a. High-quality and low-pollution briquette products. b. Good-quality briquettes at affordable prices.
Institution and Communities	a. Development of low-carbon, economically valuable agro-industrial production systems. b. Implementation of circular and environmentally friendly technologies to mitigate climate change.

Analytical Hierarchy Process Result

The analytical hierarchy process (AHP) method is used to analyze clean production strategy for carbon trading. Primary data was collected from expert respondents using the AHP method and scored from 1-9 (Figure 2). The adequacy of expert interview data will be calculated using a snowball sampling method with a total of 5 respondents. The result of analytical hierarchy process (AHP) shows penta-helix collaboration is the strongest recommendation with 0.27 AHP score for the strategy of carbon trading policy resolution. The analysis data of AHP supports carbon trading target to achieve the goals of carbon emission reduction.

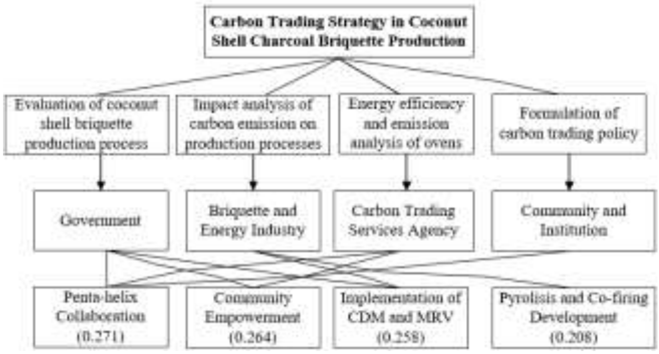

Figure 5. The result of AHP on carbon trading strategy in coconut shell and charcoal briquette production (Source: processing data, 2025)

Reliable measurement procedures are needed to establish a carbon baseline and a recognized value for emission reductions to ensure environmental integrity, clean, and efficient production (Valliere & Dunod, 2017). The AHP results indicate that barriers such as revenue uncertainty, limited technical capacity, high transaction costs, regulatory complexity, and carbon reduction strategy with incentives significantly hinder industry participation (Rico Lugo et al., 2023). These findings are consistent with global studies on carbon market adoption in emerging economies with transparency and market price accuracy as main success factors (Perdana et al., 2023).

This observation systematically translates them into targeted policy interventions, including financial risk mitigation instruments, embedded capacity-building programs, and regulatory simplification. The economic feasibility of carbon trading remains constrained by transaction costs associated with clear additionality of carbon reduction, validation processes, and compliance with international carbon standards (Widya et al., 2026). The government should facilitate carbon credit based on international standards, sectoral expansion, and international linkage reflects best practices observed in mature carbon markets (Molossi et al., 2023).

The central role of penta-helix collaboration further distinguishes this framework by embedding multi-stakeholder coordination into policy design, ensuring alignment between regulatory, industrial, scientific, and societal actors (Wahyuni et al., 2025). Indonesia's goal of achieving zero emission urgently requires strengthening strategic policy commitments across all sectors and their elements (Nurhayati et al., 2024). The findings contribute for a policy integrated system that bridges effieciency production with minimal carbon emission, circular production, and carbon market functionality for reducing carbon agro-industrial transitions in developing countries (Valliere & Dunod, 2017).

Discussion

The coconut shell charcoal briquette production system process demonstrates is strongly influenced by both material balance and operational conditions, particularly storage quality and demand-driven production cycles. The briquette industry reliance on maintaining 20–30 tons of raw coconut charcoal in the warehouse to ensure production reserves. However, storage management must control temperature and humidity can degrade material quality that affect lignin content and calorific value (Acampora et al., 2025). It means the upstream material handling plays a critical role in downstream energy performance (Velasco-Muñoz et al., 2021).

Figure 6. The discmill process of charcoal raw material (Source: Processing Data, 2025)

At the process level, the drying stage is consistently identified as the dominant emission hotspot, based on the article (Clasen et al., 2022). The emission evaluation must incorporate system-level interactions, where waste reuse and internal energy substitution significantly alter the overall sustainability profile (Bui et al., 2022).

Indeed base on the interview data, there is potential of developing carbon offset criteria from the reusing briquette reject waste to be production fuel. Revering to the analytical heararchy process (AHP), this briquette production strategy needs to be implemented and supported by the government (Miranda et al., 2021).

Integrating government policy information with academics/researchers, entrepreneurs, communities organizations, and the public ensures widespread awareness education on maintaining a low-emission lifestyle (Kaunang et al., 2025).

Conclusion

The key findings indicate that strengthening penta-helix collaboration and intensifying the socialization of clean production patterns and low-emission lifestyles are the highest priorities in supporting the effectiveness of the storage material. While the use of reject briquettes is determined as alternative energy to strenght clean and efficient production system. Penta-helix has high attention from experts with eigen vector score 0.28 to build up participation of government, agroindustries, societies, institutions, and carbon trading traders to calculate legally efficient and clean production as carbon decreasing support. The use of turbine ventilators inside material warehouse impacts the materials quality and eliminate reject briquettes as a contributor to carbon emissions during oven process. The initiative of reusing reject briquettes with small scale as alternative energy in the drying process minimize carbon waste and keep minimum cost. Integration system in th agroindustrial through an integrated platform that provides access to carbon briquette projects, measurement, reporting, verification (MRV) improve material quality control management and ineffieciency process with low carbon emission. The second observation finds that the use of turbine ventilators can reduce the risk of reject briquettes and carbon emission in the production process. The reuse of reject briquettes with controled scale as alternative energy of drying oven is positively support carbon neutral and has potential to be bargaining value carbon offset work.

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Author Contributions

For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, GE and AMF.; methodology, GE and MY.; software, GE.; validation, GE., AMF., and MY.; formal analysis, GE.; investigation, GE.; resources, GE and MY.; data curation, GE.; writing—original draft preparation, GE.; writing—review and editing, GE.; AMF,. and MY, visualization, X.X.; supervision, AMF and MY.; project administration, AMF.; funding acquisition, GE and AMF.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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