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Determinants of adoption of cattle manure briquettes: a logistic regression study among salt farmers in rural Aceh, Indonesia

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Introduction: The increasing pressure on rural energy systems and the environmental burden of unmanaged livestock waste highlight the need for locally appropriate bioenergy solutions. However, little is known about the socio-behavioral determinants driving farmers' willingness to adopt livestock-based briquettes, particularly in traditional salt-farming communities where technological transitions remain slow.
Methods: This study examines the economic, environmental, social, and policy factors influencing the adoption of cow-manure-based briquettes among salt farmers in Pidie, Aceh, Indonesia, using survey data from 56 farmers analyzed through binary logistic regression.
Results: The results indicate that policy support, economic feasibility, and environmental awareness are the strongest predictors of adoption intention, while social influence shows only marginal effects.
Discussion: These findings demonstrate that adoption is shaped less by the briquettes' technical performance and more by institutional assurance and perceived economic benefit. The study offers novel insights into energy-transition dynamics within small-scale salt production systems and provides actionable policy implications, including the need for targeted regulatory incentives, financial support schemes, and inclusive capacity-building programs. Strengthening these dimensions can accelerate the shift away from firewood dependence, reduce deforestation risks, and promote circular livestock-based bioenergy pathways in rural coastal economies.

KEYWORDS

biomass briquette, cattle manure, logistic regression, renewable energy adoption, salt farming

Introduction

Traditional salt production remains a vital livelihood for coastal communities in Aceh, particularly in regions such as Pidie Regency. In this system, salt farmers rely heavily on firewood to heat brine until it evaporates and forms salt crystals—after undergoing several preparatory steps (Athaillah and Rahmi, 2020). Because this heating process is long and requires high thermal intensity, the consumption of firewood is very high and continues to increase, making salt production one of the rural activities that places considerable pressure on local forest resources.

Evidence of forest degradation in Aceh has been widely reported in various land-use change studies. For example, an analysis of the Pocut Meurah Intan Grand Forest

Park (Tahura-PMI) showed that between 2003 and 2018, large areas of forest were converted into open land, settlements, shrubs, and agricultural areas, accompanied by a decline in secondary forest and forest plantation cover within an area of 6,215 ha. Declines in forest carbon stocks over time also indicate reduced forest quality and diminished carbon sequestration capacity (Fadhli et al., 2021). In the context of salt production, the dependence on firewood is not only an energy issue but also a significant environmental concern, particularly given the observed deforestation trend in Aceh.

To address these challenges, utilizing agricultural and livestock residues—such as cattle manure, rice husks, and sawdust—as alternative fuel in the form of biomass briquettes presents a promising solution. These residues are abundant in rural Aceh and can be processed into renewable solid fuel, reducing reliance on forest-derived firewood while simultaneously adding value to waste materials. Previous studies have shown that biomass briquettes provide competitive calorific values, stable combustion characteristics, and lower emissions compared to traditional firewood, making them suitable for long-duration heating processes like salt evaporation (Athaillah et al., 2024, 2025).

Cattle manure, often traditionally used as fertilizer or left unmanaged around farms, poses significant environmental challenges—such as greenhouse gas emissions, water contamination, and air quality degradation due to anaerobic decomposition. Consequently, innovative waste management strategies are urgently needed to transform livestock residues into value-added resources that contribute to sustainable energy development (Hoang et al., 2021; Hoang, 2021; Carter et al., 2018).

Among the emerging approaches, the conversion of cattle manure into solid biofuel briquettes offers a promising solution (Sunnu et al., 2023; Vyas et al., 2015). This process not only mitigates environmental impacts but also provides a renewable energy alternative that reduces dependence on fossil fuels and firewood (Adu-Poku et al., 2022; Akhator et al., 2023). Previous studies have reported that biomass-based briquettes exhibit favorable combustion characteristics, moderate ash content, and competitive calorific values, making them suitable for household and small-scale industrial applications (Falemara et al., 2018; Shuma and Madyira, 2019).

Although briquettes have demonstrated feasible calorific performance and lower emissions (Athaillah et al., 2024, 2025), their adoption among salt-producing households in Pidie Regency remains notably low, indicating a critical research gap in understanding the non-technical drivers of technology uptake. Preliminary community observations and local reports suggest that farmers' reluctance is shaped by intertwined social, economic, and policy constraints: long-standing cultural dependence on firewood, limited awareness of alternative fuels, fluctuating household income that restricts willingness to invest in new energy sources, and the absence of institutional support or incentives for transitioning to cleaner fuels. Despite these socio-economic realities, no empirical study has systematically examined how these community-specific factors influence acceptance and adoption decisions in Pidie's salt-farming sector. Addressing this gap is essential for developing context-appropriate energy interventions and for designing policies that can realistically shift rural households toward sustainable biomass fuel alternatives.

Therefore, the success of such biomass innovations extends beyond their technical performance; it depends critically on farmers' social acceptance and economic feasibility. Thus, this study not only focuses on optimizing briquette material composition but also examines the socioeconomic and policy factors influencing farmers' willingness to adopt cattle manure-based briquettes. The findings are expected to contribute empirical evidence to the literature on livestock waste valorization for renewable energy and support policy initiatives aimed at promoting circular livestock economies in developing regions.

In this regard, regression analysis is employed to examine the relationship between social, economic, and policy variables and the level of briquette adoption. This model facilitates the identification of the most significant factors driving or hindering technology acceptance at the farmer level. The findings are expected not only to contribute empirically to the literature on renewable energy adoption but also to offer practical recommendations for policymakers to enhance sustainable and equitable adoption of briquettes.

Materials and methods

Materials

The raw materials employed in this study consisted of dried cow manure, rice husks, wood dust, and tapioca flour as a binding agent, combined with water to ensure a uniform mixture. The formulation was adopted from Athaillah et al. (2024), comprising 74% cow manure, 5% rice husk, 9% wood dust, 1% tapioca flour, and 11% water. This composition was selected based on prior quality assessments, which demonstrated favorable stability and energy characteristics of the briquettes. The physical appearance and dimensions of the cattle manure briquettes used in this study are shown in Figure 1.

The briquette molding process was carried out using a basic pump block molding machine, with a production capacity of approximately 200 briquettes per day. The tool is equipped with two molds per press, each measuring 20 cm in length, 10 cm in width, and 16 cm in height (Athaillah et al., 2024). The homogenized mixture was placed into the molds and compressed to form solid briquettes.

Following the molding process, the briquettes were sun-dried for 20–30 days until completely dry. During this drying stage, the mass of each briquette decreased from approximately 2.5 kg in its initial wet form to around 700 g in its final dry state. This drying phase was essential to reduce the moisture content, thereby enhancing the density and combustion quality of the briquettes.

Methods

Once the drying process was completed, the briquettes were transported to local salt production sites in Pidie Regency. The first stage involved a socialization session with salt farmers, in which the objectives, benefits, and potential applications of briquettes as an alternative fuel were introduced. This session was conducted in a group setting to ensure comprehensive information sharing and active participation.

Following the socialization, a hands-on demonstration was carried out directly at the farmers' salt-processing stoves. During

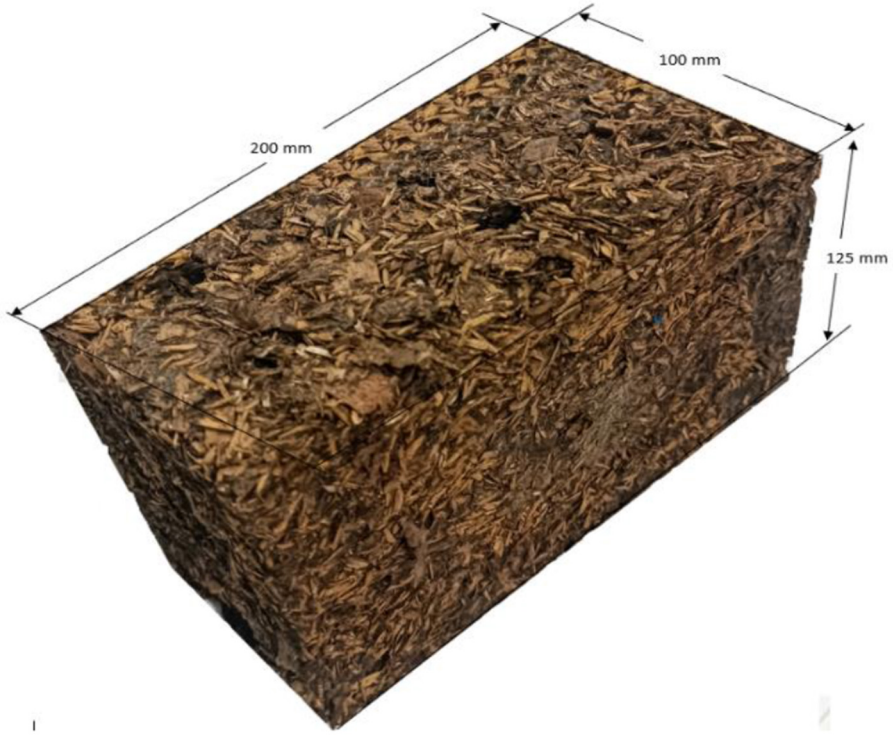

FIGURE 1
The briquette product with dimensions of 20 cm x 10 cm x 12.5 cm.

this demonstration, the briquettes were burned in the traditional salt-evaporation furnace used by the farmers. The demonstration included observing ignition, combustion stability, and heat output while processing seawater brine. The process was continued until the brine fully crystallized into salt, allowing farmers to directly evaluate whether the briquette-based heating produced salt of the same quality as that obtained using firewood. This step was essential for reducing uncertainty and providing farmers with concrete evidence that the briquettes do not alter the final salt quality.

After the socialization and demonstration stages, primary data collection was conducted through structured questionnaires distributed to the salt farmers. The questionnaire was designed to capture perceptions, acceptance levels, and the willingness of farmers to adopt briquettes as a substitute for firewood. The observed variables included social, economic, environmental, and policy dimensions, which were subsequently analyzed using regression techniques to identify the most significant factors influencing adoption decisions. The overall research workflow is illustrated in Figure 2.

Structured questionnaire description

A structured questionnaire was developed to measure four latent constructs—social influence, economic factors, environmental factors, and policy support—as predictor variables (X_1–X_4), along with farmers' willingness to adopt briquettes as the dependent variable (Y). The questionnaire used a combination of Likert-scale items for independent variables and a binary indicator for the adoption decision. A total of 56 questionnaires were distributed to salt farmers who had participated in briquette socialization and demonstration activities, and all were fully completed with no missing responses, allowing for complete-case analysis.

Measurement of independent variables (X_1–X_4)

All independent variables were measured using multi-item scales on a 5-point Likert scale, ranging from 1 = strongly disagree to 5 = strongly agree. Higher scores indicate stronger perceptions toward each construct. The four constructs were operationalized as follows:

Social influence (X_1)

Social influence captured the extent to which farmers perceived encouragement or normative pressure to adopt briquettes. It consisted of four items, including:

- Influence from fellow salt farmers
- Encouragement from local farmer groups
- Opinions of respected community leaders

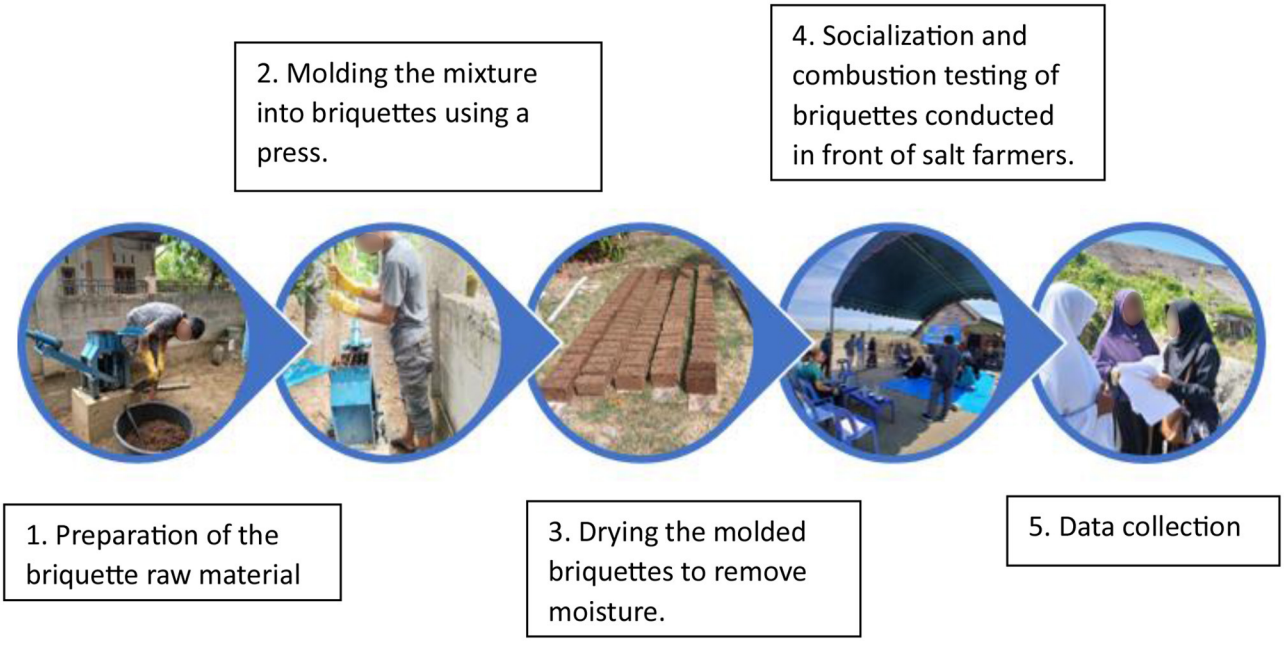

FIGURE 2
Flow of the research process.

- Perceived social expectations to adopt cleaner fuel

A composite score for X_1 was generated by averaging the four items.

Economic factors (X_2)

Economic perceptions were measured using five items assessing farmers' views regarding affordability, expected savings, and financial feasibility. The indicators included:

- Affordability of producing or purchasing briquettes
- Expected reduction in production costs
- Perceived long-term financial benefits
- Cost comparison between briquettes and firewood
- Accessibility of financial support for adopting new fuel X_2 was computed as the mean score of all economic items

Environmental factors (X_3)

Environmental awareness was assessed through five items evaluating farmers' understanding of ecological implications. Items included:

- Awareness of deforestation linked to firewood use
- Perceived environmental benefits of briquettes
- Concern about forest degradation near salt production areas
- Views on sustainability of biomass waste utilization
- Perceived role of briquettes in reducing ecological harm

The environmental factor score (X_3) was calculated by averaging all environmental items.

Policy support (X_4)

Policy factors consisted of four items reflecting institutional influence, including:

- Government encouragement to adopt briquettes
- Availability of regulatory guidance
- Exposure to training or demonstration programs
- Perceived legitimacy of technologies endorsed by government agencies The policy support score (X_4) was derived from the mean of the four items

Dependent Variable: Willingness to Adopt Briquettes (Y)

The dependent variable was categorical and measured using a binary response:

1 = willing to adopt briquettes

0 = not willing to adopt briquettes

The adoption decision was obtained after farmers participated in hands-on demonstrations, allowing them to make an informed choice.

Logistic regression modeling and data analysis

This study applied binary logistic regression analysis to identify factors influencing the willingness to adopt briquettes (Prihantini et al., 2024). Logistic regression is a statistical modeling technique used when the dependent variable is binary (Dey et al., 2025), allowing estimation of the probability of an event occurring as a function of predictor variables. The model estimates the log odds of

the dependent variable (willingness to adopt briquettes) as:

$$Log\left(\frac{p}{1-p}\right) = Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4$$

where:

Log = Logarithmic equations
p = Probability of adopting briquettes,
1- p = Probability not to adopting briquettes
Y_i = Salt Farmer's Decision
β_0 = Intercept
$\beta_1, \beta_2, \beta_3, \beta_4$ = Coefficients for the predictors
X_1 = Social factor
X_2 = Economic factor
X_3 = Environmental factor
X_4 = Policy factor

Primary data were collected from 56 salt farmers in Pidie Regency. The sample size was determined based on the fact that only this group had participated in hands-on socialization and demonstration sessions on briquette production and use, including material mixing, operation of the briquette press machine, and practical combustion during salt processing. Therefore, these respondents were considered informed users who fully understood the technical characteristics of briquettes and could provide reliable assessments of adoption potential. A purposive sampling approach was applied, which is appropriate when the research objective requires feedback from individuals with prior exposure to the technology rather than from the general farming population. Data were collected through structured interviews using a fieldtested questionnaire.

Data were analyzed using binary logistic regression, as the dependent variable represented the adoption decision (adopt = 1; not adopt = 0). Logistic regression was chosen because it is widely used in technology adoption studies to examine how social, economic, environmental and policy-related factors influence the probability of adopting an innovation. SPSS version 26 was used to estimate the model and evaluate the significance of each predictor.

A validity test was conducted to ensure that each item of the research instrument accurately measured the intended construct. The analysis employed the Pearson Product Moment Correlation (PMC), which is commonly used to assess the relationship between each item score (X) and the total score of its respective variable (Y) when the data are measured on an interval or ratio scale.

The PMC coefficient was calculated using the following formula:

$$r = \frac{n\sum XY - \left(\sum X\right)\left(\sum Y\right)}{\sqrt{\left[N\sum X^2 - \left(\sum X\right)^2\right]\left[N\sum Y^2 - \left(\sum Y\right)^2\right]}}$$

where:

- X = individual item score,
- Y = total score of the corresponding variable (e.g., social factor, economic factor, environmental factor, or policy factor),
- $\bar{X}$ and $\bar{Y}$ = mean values of X and Y.

An item was considered valid if its correlation coefficient exceeded the critical value of r at the 0.05 significance level or if the p-value < 0.05. Items that did not meet this requirement were excluded from subsequent analyses.

Prior to interpreting the results, the assumptions of logistic regression were tested. Multicollinearity was assessed using the Variance Inflation Factor (VIF) to ensure no excessive correlation among independent variables (Kutner et al., 2005). Model adequacy was evaluated with the Hosmer and Lemeshow goodness-of-fit test (Hosmer et al., 2013), while the overall significance of the model was confirmed through the omnibus test of model coefficients (Menard, 2010). The test compares the predicted probabilities generated by the model with the actual observed outcomes across decile groups.

The hypotheses for the Hosmer–Lemeshow test are:

- H0: The model fits the data (p-value > 0.05).
- H1: The model does not fit the data.

The overall significance of the logistic regression model was examined using the LikelihoodRatio (LR) Test, also known as the G^2 test, which is reported in the Omnibus Test of Model Coefficients. The hypotheses for the LR test are:

- H0: $\beta 1 = \beta_2 = \beta 3 = \beta 4 = 0$ (none of the predictors influence the outcome)
- H1: At least one $\beta_k \neq 0$, for k = 1, 2, 3, 4

The test statistic is calculated as:

$G^2 = -2 \ln L_0 - (-2 \ln L_1)$ where:

- L0 is the likelihood of the null model (all coefficients set to zero),
- L1 is the likelihood of the full model containing all predictor variables.

These procedures validated the robustness of the logistic regression model and ensured the reliability of the findings regarding social, economic, environmental and policy factors affecting briquette adoption among salt farmers.

To facilitate interpretation, each logistic regression coefficient (β) was exponentiated to yield an Odds Ratio [Exp(B)]. In logistic regression, the coefficient β represents the change in the log-odds of adopting briquettes for a one-unit increase in the predictor. By exponentiating β, Exp(B) converts this change from the log-odds scale into a ratio of probabilities, allowing practical interpretation. Therefore, Exp(B) directly reflects how social, economic, environmental, and policy factors modify the odds of willingness to adopt briquettes. Odds ratios [Exp(B)] were interpreted to understand the effect size of each predictor on the odds of willingness to adopt briquettes.

Results and discussion

Results

The validity assessment using the Pearson Product Moment showed that all predictors—social, economic, environmental, and policy factors—exhibited correlation coefficients above the critical value (r table = 0.258, n = 56), indicating that all items met the

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TABLE 1 Results of the coefficient of determination (Nagelkerke R^2).

-2 Log likelihood	Cox and Snell R Square	Nagelkerke R Square
34.647	0.506	0.689

TABLE 2 Partial test results.

Variables	B	Wald	*P*-value	Odds ratio
Social factors	**4.865**	**3.778**	**0.052**	**1.609**
Economic factors	5.724	5.010	0.025	2.100
Environmental factors	6.894	5.644	0.018	1.670
Policy factors	12.810	6.821	0.009	3.113
Constant	−23.605	12.249	0.000	0.000

Bold values indicate non-significant results ($p > 0.05$).

required validity criteria. Multicollinearity diagnostics confirmed that the predictors were independent, with tolerance values ranging from 0.636 to 0.877 and VIF values between 1.141 and 1.573, all within acceptable limits.

The logistic regression model demonstrated a satisfactory goodness of fit, as indicated by a non-significant Hosmer–Lemeshow statistic ($\chi^2 = 2.981$, $p = 0.887$), suggesting alignment between observed and predicted classifications. The results of the simultaneous parameter significance test on the final logistic regression model showed a test statistic value of 39.448 and a *p*-value of 0.000. Based on the *p*-value having a value less than the specified significance level, it was decided that H0 was rejected. This means that there is at least one predictor variable that has a significant influence on the willingness variable as the response variable.

The logistic regression analysis reveals several important insights regarding the factors that influence salt farmers' willingness to adopt briquettes as an alternative to firewood. Overall, the model shows a strong level of fit (Nagelkerke $R^2 = 0.689$), as presented in Table 1, indicating that the social, economic, environmental, and policy-related variables collectively explain nearly 69% of the variation in farmers' adoption decisions. This suggests that the decision to switch from firewood to briquettes is not random but is strongly shaped by their socioeconomic context.

Among the four predictor variables, three factors—economic conditions, environmental awareness, and government policy support—were found to have a statistically significant influence on adoption decisions, as shown in Table 2. Social factors showed a positive but statistically weaker effect. These findings reflect the real conditions observed at the research site, where farmers often express cautious interest in new energy sources but require economic justification and institutional encouragement before transitioning away from firewood.

Based on the data processing results above, it can be seen that, using a significance level of 0.05, there are three independent variables and a constant that significantly influence the willingness to adopt briquettes. Based on the results of the partial parameter significance test, the following logit model was obtained:

$$P(Y) = -23.605 + 4.865X_1 + 5.724X_2 + 6.894X_3 + 12.810\,X_4$$

TABLE 3 Odds ratio of significant variables.

Variables	B	Wald	*P*-value	Odds ratio
Economic factors	5.724	5.010	0.025	2.100
Environmental factors	6.894	5.644	0.018	1.670
Policy factors	12.810	6.821	0.009	3.113

Model interpretation

Based on the results of the logistic regression analysis that has been carried out, the percentage of salt farmers' willingness to adopt briquettes if supported by social factors, adequate economic factors, have concern for the environment and receive support from the government is 87.00%.

$$P(Y) = \frac{e^{(\beta_0+\beta_1X_{1+}\beta_2X_2+\beta_3X_3+\beta_4X_4)}}{1 + e^{(\beta_0+\beta_1X_{1+}\beta_2X_2+\beta_3X_3+\beta_4X_4)}}$$

$$P(Y) = \frac{e^{[-23.605+\ 4.865\ (1)+5.724\ (1)+6.894\ (1)+12.810\ (1)]}}{1 + e^{[-23.605+4.865\ (1)+5.724\ (1)+6.894\ (1)+12.810\ (1)]}}$$

$$P(Y) = 0.870$$

The logistic regression model was further examined by estimating the predicted probability of briquette adoption when all key enabling conditions—economic stability, environmental concern, and strong policy support—are simultaneously present. Using the estimated coefficients ($\beta 0 = -23.605$; $\beta_1 = 4.865$; $\beta_2 = 5.724$; $\beta 3 = 6.894$; $\beta_4 = 12.810$), the model yields a predicted probability of 0.870, implying that the likelihood of adoption increases to approximately 87% when farmers are influenced by social factors, adequate economic capacity, express environmental awareness, and receive explicit government support. This value indicates that the combined presence of these determinants substantially improves adoption prospects relative to baseline conditions.

The predicted probability also reflects the cumulative and mutually reinforcing nature of the three determinants. In isolation, each variable contributes positively to adoption, but their joint presence substantially amplifies the overall probability. This finding supports the multivariate premise that adoption decisions among rural producers are seldom shaped by a single factor.

Complementing the probability estimates, the odds ratio values obtained from the parameter significance test highlight the relative strength of each determinant, as presented in Table 3.

Economic considerations emerged as one of the strongest predictors of briquette adoption. Farmers with better financial capacity or perceived economic benefit were 2.10 times more likely to adopt briquettes compared to those who felt economically constrained. This aligns with field observations: farmers often cited the rising cost of firewood and the unstable availability of wood suppliers as burdens that reduced their profit margins. Briquettes, especially when sourced from locally available cattle manure, rice husk, and sawdust, offer a lower-cost alternative—yet farmers remain hesitant unless the economic advantages are clearly demonstrated.

This interpretation is highly relevant to the situation in Pidie: most salt farmers belong to lowincome groups and are extremely

sensitive to fluctuations in production costs. The price of firewood continues to rise each harvesting season—often increasing by 25–40% during peak demand—which imposes a significant financial burden. In field interviews, several farmers admitted that the high cost of firewood reduces profit margins and causes instability in salt production.

This explains why farmers are more responsive to innovations such as briquettes when they perceive clear cost-saving potential. In other words, even if briquettes are technically feasible, financial capacity and perceived economic benefits remain the primary drivers of adoption.

Environmental awareness also played a significant role, increasing adoption likelihood by 1.67 times. In discussions during data collection, many farmers acknowledged that firewood dependence contributes to forest degradation in Pidie Regency, where local forest cover has declined in recent years. Farmers who were aware of this impact, or who had experienced firsthand the increasing distance required to collect or purchase wood, were more open to transitioning to briquettes. This suggests that environmental consciousness is gradually emerging as a motivator among rural producers, reinforcing findings from other renewable energy adoption studies.

This finding aligns with the ecological context of Pidie. The long-term intensive use of firewood in salt production has contributed to vegetation degradation, especially in areas near production sites. Some interviewed farmers acknowledged that their activities—particularly purchasing wood from nearby forests—have contributed to forest depletion.

However, this awareness is not uniformly distributed. Only farmers who have participated in environmental training or mangrove rehabilitation programs showed higher sensitivity to deforestation issues. Therefore, the results reinforce existing literature that environmental awareness functions as an important motivator, but does not emerge automatically without educational interventions.

Policy factors emerged as the most dominant variable, with an odds ratio of 3.11, meaning that farmers are three times more likely to adopt briquettes when supported by government policies or interventions. This interpretation is reasonable given the context of salt farmers in Pidie.

They generally operate within traditional and informal economic structures, rely heavily on inherited practices, and have limited access to modern production technologies. As a result, technological innovations are often viewed with hesitation unless accompanied by credible support. In this setting, government-led initiatives carry a higher level of legitimacy and trust compared to those introduced by external actors. Consequently, farmers are more willing to adopt new technologies—such as briquettes—when these innovations are presented, endorsed, or facilitated through official government programs.

A clear example was observed during briquette socialization activities: farmers' participation increased significantly when sessions were labeled as official events from the relevant government agency. This demonstrates that institutional legitimacy strongly influences innovation acceptance. Furthermore, the provision of press machines, technical training, or subsidies for raw materials are key to ensuring sustainable adoption. These findings underscore the importance of policy-driven adoption, aligning with the literature on energy innovation in rural communities.

Although the results show that social factors are not statistically significant at the 0.05 level, the coefficient remains positive. This implies that social norms, farmer group influence, or opinions of local leaders still play a supporting role, albeit weaker than other factors. Field observations reveal that salt farmers in Pidie tend to be more individualistic in their production decisions. They join farmer groups mainly for administrative purposes rather than for collective decision-making. Therefore, it is unsurprising that social factors exert a weaker influence compared to economic and policy factors.

Discussion

The present study provides empirical evidence on the socio-behavioral determinants of briquette adoption among traditional salt farmers in Pidie, Aceh. The logistic regression model demonstrated strong explanatory power, indicating that adoption is not determined by a single driver but is shaped by the interplay of policy, economic and environmental factors. This multidimensional influence aligns with global findings on renewable energy adoption in rural settings, where structural conditions and institutional support consistently shape farmers' willingness to transition toward alternative technologies (Bangalore et al., 2016; Nuthall and Old, 2018; Ozoegwu and Akpan, 2021; Sovacool, 2016).

Policy factors as the most decisive driver

One of the major contributions of this study is its confirmation that *policy factors are the strongest predictor* of adoption. This is not merely a statistical outcome but is deeply rooted in the socio-economic landscape of Pidie. Salt farmers in this region operate within traditional production systems characterized by low technological exposure, limited access to capital, and strong dependency on government-led programs for livelihood support. Historically, agricultural innovations introduced through government channels have shaped farmers' perceptions of legitimacy and trust. Consequently, government-backed briquette initiatives carry significantly higher credibility than private or NGO-led interventions.

This finding is consistent with institutional theory, which posits that actors in resourceconstrained environments rely heavily on formal institutions to reduce uncertainty and perceived risk (North, 1990). Similar patterns have been documented in rural India and Nigeria, where smallholders were more likely to adopt biomass stoves or biogas units when implementation was embedded in state-sponsored extension services or regulatory mandates (Aggarwal and Chandel, 2022; Ozoegwu et al., 2017; Venkataraman et al., 2010).

What differentiates the Aceh context, however, is the *policy environment surrounding firewood*. The partial prohibition and restricted access to firewood for salt production create a regulatory pressure that directly nudges farmers toward alternative fuels. In

many global cases, regulations alone are insufficient; however, in Pidie the regulation coincides with rising firewood prices, scarcity of local forest resources, and growing community concern regarding deforestation. The combination of regulatory pressure, declining resource availability, and institutional authority thus amplifies the impact of policy interventions, explaining why the odds ratio for policy factors exceeds those of all other variables.

Economic drivers and cost–benefit considerations

Economic factors also played a significant role, which is consistent with global literature emphasizing cost–benefit calculations as a central determinant of renewable energy adoption (Liu et al., 2023; Palm and Tengvard, 2011; Tariq et al., 2022). In Pidie, firewood prices have shown seasonal surges. This cost volatility disproportionately affects small producers whose profit margins are already thin. Briquettes, in contrast, have the potential to stabilize fuel costs because their raw materials—cow manure, rice husk, and sawdust—are locally available and underutilized.

This mirrors international findings where affordability and resource accessibility determine farmers' willingness to switch from traditional to biomass-based fuels, such as in rural Ethiopia and Nepal (Katuwal, 2022; Geddafa et al., 2023). The present study adds nuance by showing that even in the absence of direct subsidies, the mere *perception* of long-term savings already increases adoption likelihood, highlighting the importance of transparent cost comparison during technology dissemination.

Environmental awareness as a supporting but not dominant factor

Environmental awareness was another significant determinant, though not as strong as policy or economic factors. This pattern is widely observed in biomass and clean-cooking literature, where environmental motivations rarely supersede economic concerns but still influence adoption when aligned with local ecological realities. In the case of Pidie, farmers' awareness of forest degradation—particularly the decline in nearby vegetation due to long-term firewood extraction—provides a contextual foundation for ecological reasoning.

However, this awareness is unevenly distributed. Only farmers who previously participated in mangrove rehabilitation or environmental extension activities demonstrated strong ecological concern. This supports findings from community energy adoption in Southeast Asia that environmental motivations depend heavily on prior exposure to ecological education and participatory conservation programs (Erlinda et al., 2024; Primahardani and Erlinda, 2025).

Social factors: marginal but present

Social factors, while positive, were only marginally significant. This contrasts with studies in rural Africa or Latin America where community norms strongly influence energy transitions (Álvarez et al., 2024; Kapfudzaruwa et al., 2017). In Pidie, salt farming is traditionally individualistic, with farmer groups functioning primarily for administrative purposes rather than collective decision-making. This structural characteristic limits the influence of peers or local leaders on technology choices. Still, social influence may become more relevant once early adopters demonstrate the practical benefits of briquettes, suggesting a potential diffusion effect in the long term.

Limitations

Several limitations should be acknowledged. First, the study is site-specific; the socio-cultural and regulatory characteristics of Pidie may not fully represent other salt-producing regions in Indonesia. Second, the study captures adoption intention at a single time point rather than longterm usage patterns. Long-term sustainability of cow-manure briquettes, including supply chain stability and durability of production equipment, remains untested.

Conclusion

This study provides empirical evidence that briquette adoption among salt farmers in Aceh is primarily shaped by policy support, followed by economic feasibility and environmental awareness, while social influences play a secondary role. The findings highlight a key contribution to the rural energy transition literature by demonstrating that in highly traditional production systems—such as coastal salt farming—policy legitimacy outweighs economic and social determinants typically found in renewable energy adoption studies. Practically, the results underscore the need for integrated policy measures that combine regulatory enforcement with incentives, targeted training, and improved market access for briquette production. Strengthening these mechanisms—especially under current conditions of rising firewood prices and ongoing coastal environmental degradation—can accelerate the shift toward cleaner and more sustainable fuel alternatives. For farmers, adoption of briquettes offers a viable pathway to reduce input costs, stabilize production, and support long-term ecological resilience in salt-farming areas.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the (patients/ participants OR patients/participants legal guardian/next of kin) was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

TA: Supervision, Conceptualization, Writing – original draft, Writing – review & editing, Investigation. MM: Project administration, Methodology, Writing – review & editing, Resources. AM: Data curation, Validation, Visualization, Software, Writing – review & editing. AR: Methodology, Project administration, Writing – review & editing. BB: Investigation, Writing – review & editing, Formal analysis. SS: Software, Writing – review & editing, Data curation.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. Generative AI tools (ChatGPT, OpenAI) were used only to assist with language editing, grammatical improvement, and refinement of academic writing style. The author(s) take full responsibility for the content, data interpretation, and all intellectual conclusions presented in the manuscript.

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References

Adu-Poku, K. A., Appiah, D., Asosega, K. A., Derkyi, N. S. A., Uba, F., Kumi, E. N., et al. (2022). Characterization of fuel and mechanical properties of charred agricultural wastes: experimental and statistical studies. *Energy Rep.* 8, 4319–4331. doi: 10.1016/j.egyr.2022.03.015

Aggarwal, R. K., and Chandel, S. S. (2022). A comprehensive review of four decades of thermally efficient biomass cookstove initiatives for sustainable development in India. *Int. J. Ambient Energy* 43, 8005–8021. doi: 10.1080/01430750.2022.2086915

Akhator, P. E., Bazuaye, L., Ewere, A., and Oshiokhai, O. (2023). Production and characterization of solid waste-derived fuel briquettes from mixed wood wastes and waste PET bottles. *Heliyon* 9:e21432. doi: 10.1016/j.heliyon.2023.e21432

Álvarez, B., Boso, À., Rodríguez-Rodríguez, I., and Espluga-Trenc, J. (2024). Engaging communities in energy transitions: a study on attitudes towards sustainable heating technologies and the role of peer effects in southern Chile. *Sustainability* 16:9115. doi: 10.3390/su16209115

Athaillah, T., Masykur, M., Husin, H., Adib, A., and Aulia, M. R. (2024). Briquettes from a mixture of cow manure, rice husks, and wood dust as alternative fuel. *J. Ecol. Eng.* 25, 290–299. doi: 10.12911/22998993/177194

Athaillah, T., Masykur, M., Husin, H., Bagio, B., and Aulia, M. R. (2025). Emission test for briquette mixture of cow manure, rice husk, and wood dust. *Int. J. Innov. Res. Sci. Stud.* 8, 922–931. doi: 10.53894/ijirss.v8i4.7975

Athaillah, T., and Rahmi, S. (2020). The effectiveness of tunnel salt construction in Pidie District, Aceh. *Russ. J. Agric. Socio-Econ. Sci.* 10, 198–205. doi: 10.18551/rjoas.2020-10.22

Bangalore, M., Hochman, G., and Zilberman, D. (2016). Policy incentives and adoption of agricultural anaerobic digestion: a survey of Europe and the United States. *Renew. Energy* 97, 559–571. doi: 10.1016/j.renene.2016.05.062

Carter, E., Shan, M., Zhong, Y., Ding, W., Zhang, Y., Baumgartner, J., et al. (2018). Development of renewable, densified biomass for household energy in China. *Energy Sustainable Dev.* 46, 42–52. doi: 10.1016/j.esd.2018.06.004

Dey, D., Haque, M. S., Islam, M. M., Aishi, U. I., Shammy, S. S., Mayen, M. S. A., et al. (2025). The proper application of logistic regression model in complex survey data: a systematic review. *BMC Med. Res. Methodol.* 25:15. doi: 10.1186/s12874-024-02454-5

Erlinda, S., Primahardani, I., and Isjoni, M. Y. R. (2024). Sustainable pro-environmental attitude: how does strategy bring it to life in coastal communities? *Int. J. Sustainable Dev. Plann.* 19, 4743–4755. doi: 10.18280/ijsdp.191221

Fadhli, R., Sugianto, S., and Syakur, S. (2021). Analisis perubahan penutupan lahan dan potensi karbon di Taman Hutan Raya Pocut Meurah Intan, Aceh Indonesia. *J. Ilmu Lingkung.* 19, 450–458. Indonesian. doi: 10.14710/jil.19.2.450-458

Falemara, B. C., Joshua, V. I., Aina, O. O., and Nuhu, R. D. (2018). Performance evaluation of the physical and combustion properties of briquettes produced from agro-wastes and wood residues. *Recycling* 3:37. doi: 10.3390/recycling3030037

Geddafa, T., Melka, Y., and Sime, G. (2023). Cost–benefit analysis and financial viability of household biogas plant investment in South Ethiopia. *Sustainable Energy Res.* 10:20. doi: 10.1186/s40807-023-00089-6

Hoang, A. T. (2021). 2-Methylfuran (MF) as a potential biofuel: a thorough review on the production pathway from biomass, combustion progress, and application in engines. *Renew. Sustain. Energy Rev.* 148:111265. doi: 10.1016/j.rser.2021.111265

Hoang, A. T., Ong, H. C., Fattah, I. R., Chong, C. T., Cheng, C. K., Sakthivel, R., et al. (2021). Progress on lignocellulosic biomass pyrolysis for biofuel production toward environmental sustainability. *Fuel Process. Technol.* 223:106997. doi: 10.1016/j.fuproc.2021.106997

Hosmer, D. W., Lemeshow, S., and Sturdivant, R. X. (2013). *Applied Logistic Regression, 3rd edn*. Hoboken, NJ: Wiley.

Kapfudzaruwa, F., Fay, J., and Hart, T. (2017). Improved cookstoves in Africa: explaining adoption patterns. *Dev. South. Afr.* 34, 548–563. doi: 10.1080/0376835X.2017.1335592

Katuwal, H. (2022). Biogas adoption in Nepal: empirical evidence from a nationwide survey. *Heliyon* 8:e10106. doi: 10.1016/j.heliyon.2022.e10106

Kutner, M. H., Nachtsheim, C. J., and Neter, J. (2005). *Applied Linear Regression Models, 4th edn*. New York, NY: McGraw-Hill/Irwin.

Liu, H., Peng, H., Yu, Z., Xia, Q., and Dong, X. (2023). Adoption of manure resource utilization technologies and its economic effects on large-scale dairy farms. *Resour. Sci.* 45, 1560–1576. doi: 10.18402/resci.2023.08.06

Menard, S. (2010). *Logistic Regression: From Introductory to Advanced Concepts and Applications*. Thousand Oaks, CA: SAGE Publications.

North, D. C. (1990). *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press.

Nuthall, P. L., and Old, K. M. (2018). Intuition: the farmers' primary decision process—a review analysis. *J. Rural Stud.* 58, 28–38. doi: 10.1016/j.jrurstud.2017.12.012

Ozoegwu, C. G., and Akpan, P. U. (2021). A review and appraisal of Nigeria's solar energy policy objectives and strategies against the backdrop of the renewable energy policy of the Economic Community of West African States. *Renew. Sustain. Energy Rev.* 143:110887. doi: 10.1016/j.rser.2021.110887

Ozoegwu, C. G., Mgbemene, C. A., and Ozor, P. A. (2017). The status of solar energy integration and policy in Nigeria. *Renew. Sustain. Energy Rev.* 70, 457–471. doi: 10.1016/j.rser.2016.11.224

Palm, J., and Tengvard, M. (2011). Motivations for and barriers to household adoption of smallscale production of electricity: examples from Sweden. *Sustainability* 7, 6–15. doi: 10.1080/15487733.2011.11908061

Prihantini, C. I., Hanani, N., Syafrial., and Asmara, R. (2024). Environmental–socioeconomic factors and technology adoption: empirical evidence from small-scale salt farmers in improving technical efficiency in the Madurese coastal area, East Java, Indonesia. *Sustainability* 16:6247. doi: 10.3390/su16146247

Primahardani, I., and Erlinda, S. (2025). Environmental citizenship: a holistic strategy to realize pro-environmental attitude sustainability for coastal communities. *J. Ilmu Lingkung.* 23, 616–631. doi: 10.14710/jil.23.3.616-631

Shuma, R., and Madyira, D. M. (2019). Emissions comparison of loose biomass briquettes with cow dung and cactus binders. *Procedia Manuf.* 35, 130–136. doi: 10.1016/j.promfg.2019.05.015

Sovacool, B. K. (2016). How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res. Soc. Sci.* 13, 202–215. doi: 10.1016/j.erss.2015.12.020

Sunnu, A. K., Adu-Poku, K. A., and Ayetor, G. K. (2023). Production and characterization of charred briquettes from various agricultural waste. *Combust. Sci. Technol.* 195, 1000–1021. doi: 10.1080/00102202.2021.1977803

Tariq, S., Safder, U., and Yoo, C. (2022). Exergy-based weighted optimization and smart decision-making for renewable energy systems considering economics, reliability, risk, and environmental assessments. *Renew. Sustain. Energy Rev.* 162:112445. doi: 10.1016/j.rser.2022.112445

Venkataraman, C., Sagar, A. D., Habib, G., Lam, N., and Smith, K. R. (2010). The Indian National Initiative for Advanced Biomass Cookstoves: the benefits of clean combustion. *Energy Sustain. Dev.* 14, 63–72. doi: 10.1016/j.esd.2010.04.005

Vyas, D., Sayyad, F., Khardiwar, M., and Kumar, S. (2015). Physicochemical properties of briquettes from different feedstock. *Curr. World Environ.* 10, 263–269. doi: 10.12944/CWE.10.1.32