

Article

The Effects of Resource Management, Technical Management, and Environmental Management on Production, Reproduction, and Economic Farm Performance Mediated by Operational Efficiency Among Madura Cattle Farmers

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Abstract

Madura cattle are a nationally important indigenous Indonesian beef cattle breed and a locally adapted genetic resource that supports smallholder livelihoods and beef production under tropical dryland, low-input farming conditions. As an indigenous Indonesian beef cattle breed raised predominantly by smallholder farmers in dryland and low-input systems, Madura cattle require integrated management practices that combine resource management, technical management, environmental management, and operational efficiency to improve farm performance. A quantitative survey was conducted with 400 farmers from Madura Island. Data were collected through structured interviews using a five-point Likert-scale questionnaire and analyzed using SEM-PLS by evaluating the measurement and structural models. The results show that all constructs met validity and reliability criteria. The model demonstrated adequate explanatory power, with adjusted R^2 values of 0.369 for Operational Efficiency and 0.522 for Farm Performance. Resource Management, Technical Management, and Environmental Management had positive and significant effects on Operational Efficiency. Operational Efficiency also had a positive and significant effect on Farm Performance and partially mediated the relationships between the three management variables and Farm Performance. These findings indicate that improving Madura cattle farming performance requires stronger resource, technical, and environmental management supported by operational efficiency as a strategic mechanism to enhance production, reproduction, and economic performance sustainably.

Keywords: Madura cattle; smallholder farmer; resource management; technical management; environmental management; operational efficiency; farm performance; mediation



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1. Introduction

Smallholder cattle farming remains central to rural livelihoods, food systems, and local economic resilience, yet its performance is shaped by a complex interaction of production, nutrition, animal health, and environmental conditions [1]. Recent studies have emphasized that cattle systems should be understood as integrated socio-ecological systems rather than as purely production units, because limited farmer training, weak on-farm infrastructure, disease pressure, and input constraints can jointly suppress productivity and income. Madura cattle are an indigenous Indonesian beef cattle breed commonly described as a stabilized composite or hybrid involving zebu (*Bos indicus*) and banteng/Bali-related *Bos javanicus* ancestry [2]. This breed is widely raised by smallholder farmers on Madura Island and is valued for its adaptability to tropical environments, tolerance of low-input management, ability to utilize relatively low-quality local feed resources, and role in household-based beef production. Beyond their production function, Madura cattle also have strong socio-cultural importance in Madura through traditional practices such as Karapan cattle racing and Sonok cattle contests, making the breed both an agricultural genetic resource and a cultural asset [3]. In dryland farming systems, however, Madura cattle farmers face resource constraints such as seasonal forage scarcity, limited water availability, restricted capital, and dependence on crop residues and family labor, making resource, technical, and environmental management particularly important for farm performance [4]. Economic factors also play an important role in shaping smallholder cattle enterprises. In Madura cattle farming, limited operating capital, feed and input costs, cattle price fluctuations, market access, veterinary and breeding costs, and household income needs influence farmers' management decisions and farm performance. Therefore, Madura cattle farming should be understood not only as a technical production system, but also as a household-based economic enterprise shaped by resource, market, and livelihood conditions [5].

At the same time, sustainable livestock development is increasingly framed by international agendas such as the Food and Agriculture Organization (FAO) Global Agenda for Sustainable Livestock and SDG 2 [6], which emphasize food and nutrition security, smallholder livelihoods, sustainable agriculture, animal health and welfare, and responsible climate and natural resource use. In this context, ruminant production systems are expected to improve productivity while also managing manure, recovering nutrients, reducing methane and manure-related greenhouse gas emissions, and addressing dry-season constraints such as feed scarcity and water use [7].

Within this broader debate, three management domains appear especially important for cattle-farm success: resource management, technical management, and environmental management [8]. Recent studies show that feed, water, breeding, and feces-related innovations are essential for the sustainability of beef cattle farming in dry and resource-constrained regions, while agroecological assessments of smallholder dairy systems indicate that better-managed production systems can perform more favorably on multidimensional sustainability criteria [9]. In parallel, recent reviews on cattle farming also show that manure management and environmental practices are no longer peripheral concerns; they are increasingly viewed as core components of efficient and sustainable livestock production [10,11].

However, much recent research has focused only on one side of the problem, such as the interactions among feed availability, water access, animal health, disease pressure, manure management, farmer decision-making, productivity, and income, rather than testing integrated farm-level performance models [12]. Furthermore, research using structural models in livestock contexts often centers on behavioral or entrepreneurial constructions, with mediators such as resilience, rather than examining whether operational efficiency

is a mechanism by which concrete farm management practices translate into better farm outcomes. Despite the growing interest in tropical and indigenous cattle systems, empirical evidence remains limited on how resource, technical, and environmental management together shape farm performance in smallholder farming systems in Indonesia [8]. Madura cattle are an indigenous Indonesian cattle breed widely raised by smallholder farmers on Madura Island and are known for their adaptability to tropical environments, relatively low-quality feed resources, and traditional low-input farming systems [13,14]. However, cattle farming in Madura is also constrained by dry-area conditions, including limited forage availability, seasonal water scarcity, calcareous soils, and low natural carrying capacity, making resource, technical, and environmental management particularly important for farm performance. In this study, smallholder cattle farming refers to a household-based and low-input cattle production system characterized by small herd size, family labor, limited land and capital resources, reliance on locally available feed, and close integration with crop farming and rural livelihood strategies.

This study addresses that gap by proposing and testing an integrated model in which Resource Management, Technical Management, and Environmental Management affect Farm Performance both directly and indirectly through Operational Efficiency among Madura cattle farmers. The study is important because it moves beyond single-factor explanations of livestock performance and positions operational efficiency as a strategic mediating capability linking day-to-day farm management with production, reproduction, and economic outcomes. By focusing on Madura cattle farming, this article also extends the discussion on sustainable smallholder livestock systems to a locally important but internationally underexamined beef-cattle context.

2. Theoretical Framework and Hypotheses Development

Recent studies show that the performance of cattle farming businesses cannot be explained only by production outputs but must be understood as the result of interactions among resource management, technical practices, environmental governance, and the ability of farmers to convert inputs into productive, efficient, and sustainable outputs [15]. One Health-based studies confirm that the people's cattle farming system is a complex system, as the factors of feed, water, livestock health, disease, environment, and managerial decisions affect each other. On the other hand, studies on beef and dairy farms also show that the integration of practices that align livestock nutritional needs, forage availability, environmental management, and business management can improve economic performance, environment, and business sustainability. On that basis, this study places Resource Management, Technical Management, and Environmental Management as the main antecedent for Operational Efficiency and Farm Performance [16].

Figure 1 presents the proposed conceptual model of the study. The model assumes that Resource Management, Technical Management, and Environmental Management influence Farm Performance both directly and indirectly through Operational Efficiency. The following subsections develop the theoretical arguments and hypotheses for each proposed relationship.

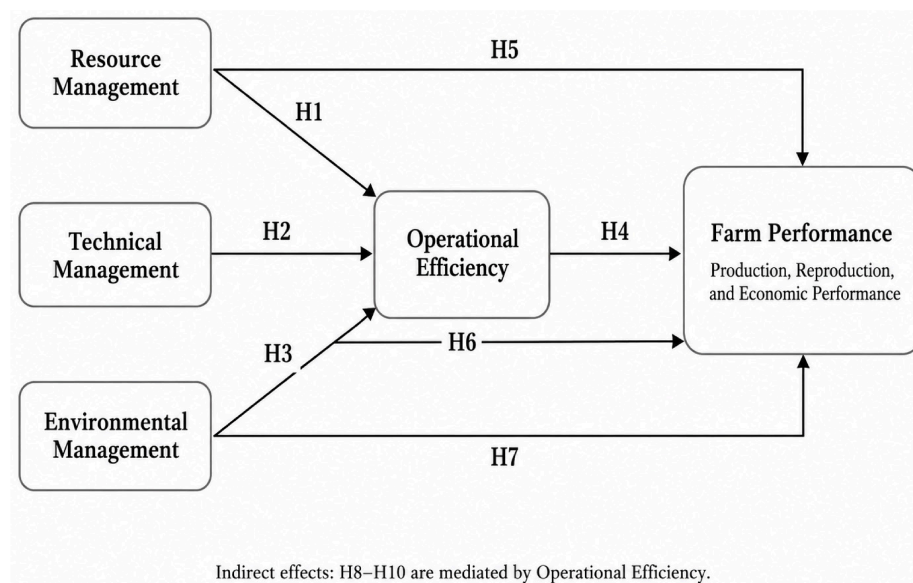


Figure 1. Proposed conceptual model. The conceptual model illustrates the proposed direct effects of Resource Management, Technical Management, and Environmental Management on Farm Performance, as well as their indirect effects mediated by Operational Efficiency. Farm Performance in this study refers to production, reproduction, and economic performance among Madura cattle farmers.

2.1. Resource Management and Operational Efficiency

In the present study, Resource Management refers to the ability of Madura cattle farmers to plan, allocate, and utilize key farm resources, including land, water, locally available feed materials, crop residues, and other household or farm assets, to support cattle production efficiently. In dryland smallholder cattle systems, this construct also includes farmers' capacity to adapt resource use to seasonal constraints, particularly limited forage availability and water scarcity during the dry season. Therefore, Resource Management is understood not merely as resource ownership, but as the managerial capability to use available resources efficiently, reduce waste, and maintain the continuity of cattle farming operations.

This relationship can be explained through the Resource-Based View (RBV), which argues that organizational performance depends not only on the possession of resources, but also on how resources are organized, deployed, and converted into productive capabilities. Applied to smallholder cattle farming, land, water, feed resources, crop residues, labor, housing facilities, and farm capital can improve farm operations only when farmers manage them efficiently. Thus, better Resource Management is expected to improve Operational Efficiency by enabling farmers to optimize the use of key inputs, reduce resource waste, and maintain smoother daily cattle farming activities.

Recent literature shows that good resource management contributes to increased productivity while reducing pressure on land and water use. Nyawira, et al. [17] reported that the use of quality forage in small-scale dairy farms in Tanzania increased milk productivity while reducing land and water footprints, while studies on silvopastoral systems in the Peruvian Amazon show that better agroecological systems tend to have stronger resource management than conventional systems. These findings indicate that better resource management tends to improve operational efficiency because key inputs can be used more optimally [17]. Based on the above theoretical arguments, this study proposes Hypothesis 1 (H1), which predicts that better management of land, water, locally available feed resources, crop residues, and other farm assets will improve farmers' ability to operate their cattle farms more efficiently.

H1. Resource Management has a positive and significant effect on Operational Efficiency.

2.2. Technical Management and Operational Efficiency

In the present study, Technical Management refers to the ability of Madura cattle farmers to apply appropriate daily husbandry practices that directly affect cattle health, productivity, and the smoothness of farm operations. This construct includes housing management, feeding practices, animal health monitoring, disease prevention, sanitation, breeding-related practices, and routine cattle care. Housing/pen management refers to the routine management of cattle housing conditions, including cleanliness, ventilation, drainage, floor condition, space adequacy, waste removal, and housing comfort. Therefore, Technical Management is understood as the practical managerial capability that enables farmers to maintain cattle properly, reduce production disruptions, and improve the efficiency of day-to-day farming activities.

A recent study on small-scale dairy farms in Kenya shows that feeding practices and livestock health conditions are significantly related to daily milk production [18]. In addition, research on environmentally sustainable beef cattle farming practices in dry regions of Indonesia shows that innovations in the aspects of feed, water, reproduction, and fecal management are important elements for business sustainability [8]. The literature on *precision livestock farming* also confirms that better monitoring-based technical management and decisions can improve the efficiency, welfare of livestock, and the sustainability of farm operations. Thus, the better the technical management that farmers implement, the greater the chance of increasing operational efficiency [19]. Based on the above theoretical arguments, this study proposes Hypothesis 2 (H2), which predicts that better application of daily husbandry practices, including housing/pen management, feeding practices, animal health monitoring, disease prevention, sanitation, and routine cattle care, will improve operational efficiency among Madura cattle farmers.

H2. Technical Management has a positive and significant effect on Operational Efficiency.

2.3. Waste and Environmental Management and Operational Efficiency

In the present study, Waste and Environmental Management refers to the ability of Madura cattle farmers to manage manure, urine, leftover feed, wastewater, housing sanitation, odor, drainage, pollution risks, and nutrient recovery in daily cattle farming operations. This construct focuses on farm-level waste handling and environmental sanitation practices rather than the broader concept of environmental management. Therefore, Waste and Environmental Management is understood as a managerial capability that helps farmers reduce pollution, maintain housing hygiene, minimize nutrient losses, and convert livestock waste into useful resources, such as organic fertilizer.

Effective manure and livestock waste management can improve operational efficiency by reducing waste accumulation, improving housing cleanliness, lowering health-related disruptions, and enabling the reuse of manure and organic residues within crop–livestock systems. In dryland smallholder cattle farming, such practices are particularly relevant because manure can contribute to soil fertility and reduce dependence on external inputs. Thus, Waste and Environmental Management is expected to support more efficient farm operations by transforming waste from a potential environmental burden into a productive farm resource.

Recent research shows that better waste management can reduce nitrogen loss, improve nutrient utilization efficiency, and promote a more sustainable business system. Qu, et al. [20] show that the right combination of waste management technology can significantly reduce nitrogen loss and improve nutrient utilization efficiency at the farming level. At the same time, other studies emphasize that the governance and resource utilization of

livestock waste is essential to convert negative externalities into more positive economic and ecological values [21]. Thus, good environmental management not only reduces the burden of pollution but also has the potential to increase the operational efficiency of livestock businesses. Based on the above theoretical arguments, this study proposes Hypothesis 3 (H3), which predicts that better environmental management, including manure handling, waste utilization, pollution prevention, sanitation, and nutrient recovery, will improve operational efficiency among Madura cattle farmers.

H3. *Environmental Management has a positive and significant effect on Operational Efficiency.*

2.4. Operational Efficiency and Farm Performance

In the present study, Operational Efficiency refers to the ability of Madura cattle farmers to use production inputs, feed, labor, cattle housing facilities, time, and locally available farm resources in a cost-effective and productive manner. A farm is considered operationally efficient when farmers can minimize input waste, control operational costs, optimize feed use, organize family or hired labor effectively, utilize housing facilities and farm assets properly, and maintain smooth daily cattle farming activities. Therefore, Operational Efficiency is not limited to financial cost reduction but also reflects the farmer's managerial capability to convert limited resources into better production, reproduction, and economic outcomes.

A recent study in Indonesia confirms that milk production and technical efficiency of smallholder farms are influenced by key inputs such as concentrated feed, pasture area, number of lactating livestock, labor, and cattle housing facilities [22]. Another study on integrated farming systems shows that good management synergy can increase production and net income substantially. In addition, studies on beef cattle farms in France show that there is a strong positive relationship between economic performance, environmental performance, and animal welfare performance when business practices are managed in a more synchronous and efficient manner. Therefore, operational efficiency is suspected to be a direct driver of improved *farm performance* [15,16]. Based on the above theoretical arguments, this study proposes Hypothesis 4 (H4), which predicts that more efficient use of feed, labor, facilities, and other farm resources will improve production, reproduction, and economic farm performance.

H4. *Operational Efficiency has a positive and significant effect on Farm Performance.*

2.5. Resource Management and Farm Performance

The performance of livestock farms is strongly influenced by farmers' ability to ensure the availability and effective use of key farm resources, including land, water, locally available feed materials, crop residues, cattle herd, family labor, housing facilities, and limited farm capital. Studies on small-scale dairy farms in Tanzania show that improving forage sources can increase productivity while reducing land and water use pressures [17]. Meanwhile, studies on silvopastoral systems in Peru show that better systems in resource management have higher agroecological performance than conventional systems [9]. Research on beef cattle farms in dry regions of Indonesia also confirms that innovations related to feed and water are important aspects in supporting the sustainability of cattle farms [8]. These findings lead to the assumption that better resource management will strengthen the production, reproduction, and economics performance of livestock businesses. Based on the above theoretical arguments, this study proposes Hypothesis 5 (H5), which predicts that better management of key farm resources, including land, water, locally available feed materials, crop residues, cattle herd, family labor, housing facilities, and farm capital,

will improve production, reproduction, and economic farm performance among Madura cattle farmers.

H5. *Resource Management has a positive and significant effect on Farm Performance.*

2.6. Technical Management and Farm Performance

The relationship between technical management and farm performance is particularly strong in the livestock literature. Studies on smallholder dairy farms in Kenya show that feeding practices, Body Condition Score (BCS), and disease status, including mastitis, are significantly associated with daily milk yield [18]. Another study in Maasai farming communities in Tanzania found that livestock extension programs that improve access to training, inputs, and better agricultural practices contribute to increased milk production and household income [23]. In addition, Mysko, Minviel, Veysset and Veissier [15] show that practices that synchronize livestock nutritional needs with forage availability are an important strategy for achieving simultaneous economic, environmental, and animal welfare performance. Thus, the better technical management is implemented, the more likely it is to improve farm performance. Based on the above theoretical arguments, this study proposes Hypothesis 6 (H6), which predicts that better technical management, including housing/pen management, feeding practices, animal health monitoring, disease prevention, sanitation, breeding-related practices, and routine cattle care, will improve production, reproduction, and economic farm performance among Madura cattle farmers.

H6. *Technical Management has a positive and significant effect on Farm Performance.*

2.7. Environmental Management and Farm Performance

In the present study, Environmental Management refers to the ability of Madura cattle farmers to manage the environmental aspects of cattle farming, particularly manure handling, waste utilization, sanitation, pollution prevention, odor control, drainage management, and nutrient recovery. This construct emphasizes how farmers reduce the negative environmental impacts of cattle farming while converting waste into useful resources, such as organic fertilizer. Therefore, Environmental Management is understood as a farm-level managerial capability that supports cleaner production, improves housing sanitation, reduces environmental pressure, and contributes to sustainable production, reproduction, and economic farm performance.

Although it is often placed as a supporting aspect, environmental management is increasingly recognized as an important determinant of livestock business performance. Effective manure and livestock waste management includes the regular collection, proper storage, safe handling, processing, and utilization of cattle manure, urine, bedding residues, wastewater, and leftover feed to maintain housing sanitation, reduce odor and pollution, minimize nutrient losses, and convert waste into useful resources such as organic fertilizer. Qu, Groot and Zhang [20] show that improved waste management can improve nutrient utilization efficiency and shift environmental *trade-off* relationships in a more favorable direction. At a broader level, good livestock waste management is also seen as important to turn waste into a source of energy or valuable resources in the context of a circular economy [21]. Therefore, good environmental management is expected not only to reduce the negative impact of business, but also to strengthen the economic performance and sustainability of livestock businesses. Based on the above theoretical arguments, this study proposes Hypothesis 7 (H7), which predicts that better manure handling, waste utilization, sanitation, pollution prevention, drainage management, and nutrient recovery will improve production, reproduction, and economic farm performance among Madura cattle farmers.

H7. *Environmental Management has a positive and significant effect on Farm Performance.*

2.8. The Role of Operational Efficiency Mediation

Theoretically, the influence of Resource Management, Technical Management, and Environmental Management on Farm Performance does not always occur directly. In many smallholder cattle systems, better management practices first improve the allocation of specific farm inputs, including locally available forage, crop residues, concentrate feed, water, family or hired labor, veterinary inputs, breeding services, cattle housing facilities, and operating capital. These improvements help reduce waste, streamline daily operations, optimize the use of feed, labor, land, water, and facilities, and ultimately strengthen production, reproduction, and economic farm performance [19]. The literature on precision farming, crop-livestock integration, and waste management shows a consistent pattern: improving management practices typically strengthens system efficiency first, and then that efficiency becomes an important channel for increased productivity, profitability, and business sustainability [16,20,22]. Although explicit evidence on operational efficiency mediation in smallholder cattle farmers is relatively limited, recent findings provide a solid basis for examining the role of such mediation in the context of Madura cattle farmers. Based on the above theoretical arguments, this study proposes three mediation hypotheses. These hypotheses examine whether Operational Efficiency functions as a mediating mechanism through which Resource Management, Technical Management, and Environmental Management contribute to production, reproduction, and economic Farm Performance among Madura cattle farmers.

H8. *Operational Efficiency mediates the influence of Resource Management on Farm Performance.*

H9. *Operational Efficiency mediates the influence of Technical Management on Farm Performance.*

H10. *Operational Efficiency mediates the influence of Environmental Management on Farm Performance.*

3. Materials and Methods

3.1. Research Design and Study Area

This study uses a quantitative approach with an explanatory cross-sectional survey design. This design was chosen because the purpose of this study is to test the causal relationship between latent constructs, namely Resource Management, Technical Management, Environmental Management, Operational Efficiency, and Farm Performance, based on the perceptions and business conditions reported by Madura cattle farmers. The research instrument was developed from the five latent constructs and includes 46 indicators, which include aspects of land use, water and climate, livestock maintenance, feed management, waste management, cost efficiency, feed efficiency, labor efficiency, resource efficiency, and production, reproduction, and economic productivity. The research was carried out in four districts on Madura Island, namely Bangkalan, Sampang, Pamekasan, and Sumenep, with an analysis unit in the form of Madura cattle farmers (Figure 2). The use of cross-sectional survey designs and structured instruments is also in line with the latest research practices in the study of livestock farmers and livestock business households that test latent constructs based on business perception and behavior [24–26].

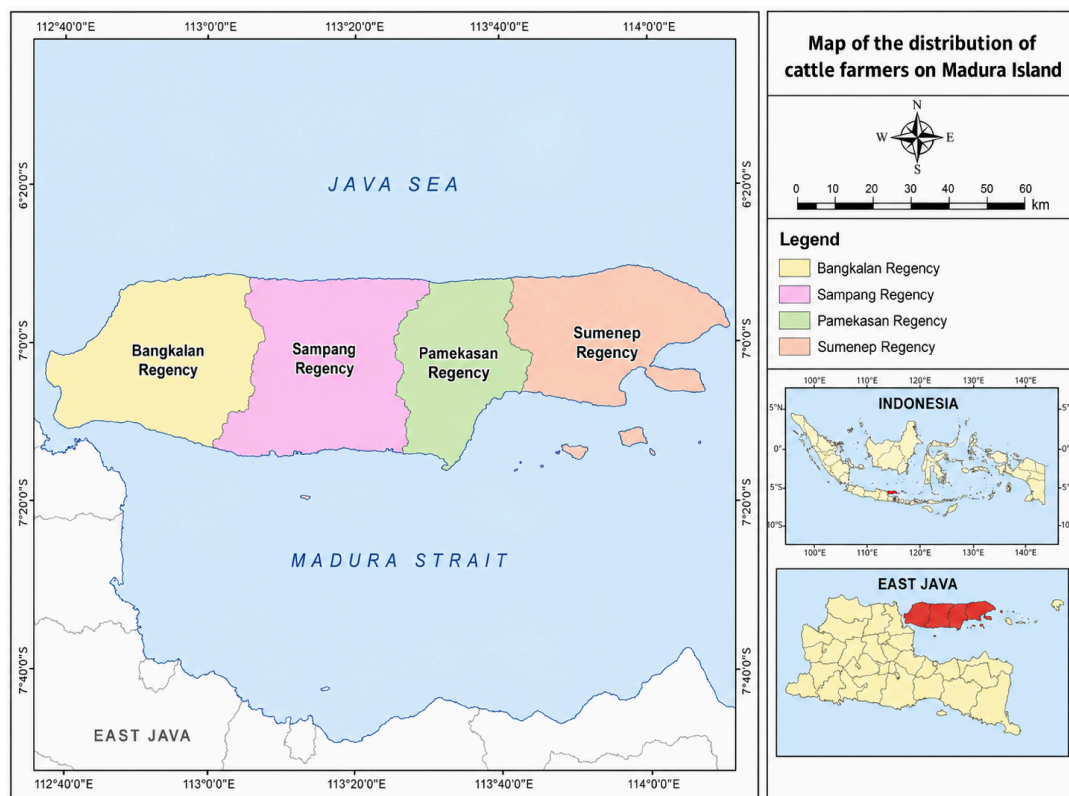


Figure 2. Location map of the study area on Madura Island, East Java, Indonesia. Source: Original figure created by the authors.

3.2. Measurement Tool Development

The questionnaire instrument used in the interviews was developed based on previous literature, the context of Madura smallholder cattle farming, expert review, and pre-testing with farmers outside the final sample. The final instrument included 46 indicators representing five constructs: Resource Management was measured using 10 indicators, Technical Management using 10 indicators, Waste and Environmental Management using 5 indicators, Operational Efficiency using 12 indicators, and Farm Performance using 9 indicators. All indicators were measured using a five-point Likert scale. To improve transparency and reproducibility, the full questionnaire instrument used in the farmer interviews is provided as Supplementary Materials.

The measurement instrument was developed through several stages to ensure its content relevance and contextual suitability for Madura cattle farming. First, an initial pool of indicators was generated based on previous literature on smallholder cattle farming, resource management, technical husbandry practices, manure and waste management, operational efficiency, and farm performance. The indicators were then adapted to the local context of Madura cattle farming, particularly dryland conditions, locally available feed resources, crop residues, housing/pen management, family labor, manure utilization, and cattle–crop integration.

Second, the initial indicators were reviewed by experts in animal science, livestock management, agricultural economics, and smallholder farming systems to assess content validity, clarity, and relevance to the five latent constructs. Based on the expert review, several items were revised to avoid overlap, improve wording, and ensure that each item reflected only one construct. Third, a pilot test was conducted with Madura cattle farmers who were not included in the final sample. The pilot test aimed to evaluate whether respondents could understand the questionnaire items, response options, and five-point Likert scale consistently. Items that were ambiguous or difficult for farmers to understand

were reworded using simpler and more context-specific language. After these stages, the final questionnaire consisted of 46 indicators distributed across five constructs (Table 1): Resource Management (10 indicators), Technical Management (10 indicators), Waste and Environmental Management (5 indicators), Operational Efficiency (12 indicators), and Farm Performance (9 indicators).

Table 1. Questionnaire indicators.

Construct	Code	Indicator Description
Resource Management	RM.01	The farmer can plan the use of available land for cattle farming activities.
Resource Management	RM.02	The farmer can manage water availability for cattle drinking and housing sanitation.
Resource Management	RM.03	The farmer can plan forage availability for cattle feed.
Resource Management	RM.04	The farmer utilizes locally available feed resources efficiently.
Resource Management	RM.05	The farmer utilizes crop residues as alternative cattle feed.
Resource Management	RM.06	The farmer prepares or stores feed reserves for the dry season.
Resource Management	RM.07	The farmer manages family or hired labor effectively in cattle farming activities.
Resource Management	RM.08	The farmer manages operating capital for cattle farming needs.
Resource Management	RM.09	The farmer uses cattle housing facilities and farm assets effectively.
Resource Management	RM.10	The farmer integrates cattle farming with crop farming or other household farming activities.
Technical Management	TM.01	The farmer applies regular feeding practices according to cattle needs.
Technical Management	TM.02	The farmer provides feed in sufficient quantity and quality.
Technical Management	TM.03	The farmer maintains the cleanliness of cattle housing or pens.
Technical Management	TM.04	The farmer ensures adequate ventilation, drainage, and comfort in cattle housing.
Technical Management	TM.05	The farmer monitors cattle health conditions regularly.
Technical Management	TM.06	The farmer applies disease prevention practices, such as sanitation, deworming, vaccination, or veterinary consultation when needed.
Technical Management	TM.07	The farmer manages breeding or mating practices properly.
Technical Management	TM.08	The farmer observes reproductive signs and reproductive performance of cattle.
Technical Management	TM.09	The farmer observes cattle body condition and growth condition.
Technical Management	TM.10	The farmer carries out routine cattle care and handling properly.
Waste and Environmental Management	WEM.01	The farmer collects manure and livestock waste regularly.
Waste and Environmental Management	WEM.02	The farmer stores manure and livestock waste properly to reduce pollution and odor.
Waste and Environmental Management	WEM.03	The farmer processes manure into compost or organic fertilizer.
Waste and Environmental Management	WEM.04	The farmer manages wastewater, drainage, and leftover feed to maintain housing sanitation.
Waste and Environmental Management	WEM.05	The farmer utilizes livestock waste for productive purposes, such as organic fertilizer or biogas where feasible.

Table 1. *Cont.*

Construct	Code	Indicator Description
Operational Efficiency	OE.01	The farmer is able to reduce feed waste in daily cattle farming operations.
Operational Efficiency	OE.02	The farmer uses local feed resources efficiently.
Operational Efficiency	OE.03	The farmer manages water use efficiently for cattle and housing sanitation.
Operational Efficiency	OE.04	The farmer uses family or hired labor efficiently.
Operational Efficiency	OE.05	The farmer uses cattle housing facilities and farm assets efficiently.
Operational Efficiency	OE.06	The farmer controls daily operational costs effectively.
Operational Efficiency	OE.07	The farmer organizes daily cattle farming activities in a timely and efficient manner.
Operational Efficiency	OE.08	The farmer minimizes production disruptions caused by poor feeding, poor sanitation, or animal health problems.
Operational Efficiency	OE.09	The farmer plans the use of inputs such as feed, water, labor, veterinary services, and breeding services efficiently.
Operational Efficiency	OE.10	The farmer reuses manure or organic waste to reduce waste and support farm productivity.
Operational Efficiency	OE.11	The farmer is able to convert limited farm inputs into productive cattle farming outcomes.
Operational Efficiency	OE.12	The farmer maintains smooth and cost-effective daily cattle farming operations.
Farm Performance	FP.01	The farmer perceives that cattle productivity has improved.
Farm Performance	FP.02	The farmer perceives that herd growth or cattle population development has improved.
Farm Performance	FP.03	The farmer perceives that cattle body condition or growth performance has improved.
Farm Performance	FP.04	The farmer perceives that breeding success has improved.
Farm Performance	FP.05	The farmer perceives that calving performance or reproductive continuity has improved.
Farm Performance	FP.06	The farmer perceives that herd regeneration has improved.
Farm Performance	FP.07	The farmer perceives that income from cattle farming has improved.
Farm Performance	FP.08	The farmer perceives that the cost–benefit outcome of cattle farming has improved.
Farm Performance	FP.09	The farmer perceives that cattle farming contributes positively to household livelihood and business continuity.

Notes: RM = Resource Management; TM = Technical Management; WEM = Waste and Environmental Management; OE = Operational Efficiency; FP = Farm Performance.

3.3. Sampling Procedure and Data Collection

Primary data were collected through face-to-face interviews using a structured questionnaire. This study applied a multistage proportional random sampling procedure. The sampling frame consisted of lists of active Madura cattle farmers obtained from livestock farmer groups, village administrations, and local livestock agency records in the four districts of Madura Island, namely Bangkalan, Sampang, Pamekasan, and Sumenep. Active farmers were defined as individuals who were currently raising Madura cattle, directly involved in daily cattle management, and had at least one year of cattle farming experience.

The sampling procedure was conducted in three stages. In the first stage, the four districts of Madura Island were selected purposively because they represent the main geographical and production areas of Madura cattle farming. In the second stage, the total sample of 400 farmers was allocated proportionally to each district based on the distribution of active cattle farmers in the sampling frame. The final sample consisted of 121 farmers from Bangkalan, 95 from Sampang, 94 from Pamekasan, and 90 from Sumenep. These allocations corresponded to 30.25%, 23.75%, 23.50%, and 22.50% of the total sample, respectively. In the third stage, respondents in each district were selected systematically from the available farmer lists. The sampling interval in each district was determined by dividing the number of eligible farmers in the district-level sampling frame by the allocated sample size for that district. If a selected farmer did not meet the inclusion criteria or was unavailable during data collection, the next eligible farmer on the list was selected.

Face-to-face interviews were chosen to ensure each question item was uniformly understood by respondents and to minimize missing responses. This approach is commonly used in farmer surveys, especially when the study relies on business perception, practice, and decision data collected through a closed-ended questionnaire. Each indicator was measured using a five-point Likert scale, namely 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. The use of structured questionnaires, in-person interviews, and a five-point Likert scale is also consistent with recent empirical research practices on smallholder farmers and ranchers that assess business attitudes, perceptions, and behaviors at the household level [24,25].

3.4. Ethical Considerations

This study was conducted in accordance with applicable ethical standards for social and humanities research and was approved by the Social Humanities Research Ethics Committee of Universitas Islam Madura under approval number 121/LPPM-UIM/I/2026. Prior to data collection, all respondents were informed about the purpose of the study, the voluntary nature of their participation, and the confidentiality of their responses. Informed consent was obtained from all respondents before the interviews were conducted.

3.5. Data Analysis

The data that has been collected is first checked for completeness, encoded, and then tabulated for statistical analysis purposes. The analysis is carried out in two stages. The first stage is a descriptive analysis to describe the characteristics of the respondents and the tendencies of the answers to each construct. The second stage is an inferential analysis using Structural Equation Modeling–Partial Least Squares (SEM-PLS) to test the direct and indirect relationships between variables according to the research model. The selection of SEM-PLS is based on several methodological considerations: this method is appropriate for relatively complex, prediction-oriented models, does not demand strict normality assumptions such as CB-SEM, and is relevant when the research involves composite constructs, higher-order constructs, or a combination of reflective and formative measurements. In the context of this study, SEM-PLS is seen as appropriate because the model connects several managerial constructs at once and places Operational Efficiency as a mediating variable [27,28].

The evaluation of the SEM-PLS model was carried out through measurement model testing and structural model testing. In the measurement model, for reflective constructs, evaluation was carried out on indicator reliability, construct reliability, convergent validity, and discriminant validity. Convergent reliability and validity were evaluated through outer loading, composite reliability, and average variance extracted (AVE), while discriminant validity was evaluated primarily using heterotrait–monotrait ratio (HTMT). Following

current best practices, measurement quality evaluation should not rely solely on a single index, but rather use several criteria together and, if necessary, consider bootstrapped confidence intervals. If at the final stage several constructs are positioned as composite constructs or higher orders, additional evaluation is carried out on the collinearity of the indicator as well as the significance and relevance of the outer weights [29–31].

After the measurement model met the required criteria, the structural model was evaluated using path coefficients, coefficient of determination (R^2), effect size (f^2), and predictive relevance. The significance of direct and indirect effects was tested using a non-parametric bootstrapping procedure with 5000 resamples. This procedure generated standard errors, t-statistics, and *p*-values for the direct paths and the mediation effects. The mediation analysis focused on whether Operational Efficiency mediated the relationships between Resource Management, Technical Management, and Waste and Environmental Management with Farm Performance. In this study, variation among producers was analyzed through differences in their scores on the latent constructs included in the SEM-PLS model. The structural model assessed whether differences in Resource Management, Technical Management, and Waste and Environmental Management were associated with differences in Operational Efficiency and Farm Performance. Demographic variables, including age, education or occupational background, farm location, and farming experience, were collected to describe respondent characteristics. However, these demographic variables were not specified as primary predictors or moderators in the main structural model because the study focused on management-related mechanisms affecting farm performance [32–34].

4. Results

4.1. Respondent Characteristic

Table 2 presents the demographic and background characteristics of the 400 Madura cattle farmers included in the study. Based on age distribution, 71 respondents (17.75%) were 21–30 years old, 102 respondents (25.50%) were 31–40 years old, 111 respondents (27.75%) were 41–50 years old, and 116 respondents (29.00%) were more than 50 years old. This distribution indicates that the respondents were dominated by middle-aged and older farmers. The respondent background variables also included educational/occupational background and cattle-farming experience. The educational/occupational background variable was clarified in the revised manuscript to distinguish formal education from livelihood or employment categories. Farming experience was included because farmers' practical experience may influence their ability to manage feed, water, labor, animal health, housing, manure, and daily operational activities. In this study, 109 respondents (27.25%) had 1–5 years of cattle-farming experience, 11 respondents (2.75%) had 6–10 years of experience, and 280 respondents (70.00%) had more than 10 years of experience. This suggests that most respondents had substantial practical exposure to Madura cattle farming, although less experienced farmers may differ from more experienced farmers in the stability and depth of their management perceptions.

These findings show that the Madura cattle farming business in the study sample is managed by respondents who are quite diverse in terms of age, region, and business experience. The dominance of middle-aged and older respondents suggests that Madura cattle farming is still largely supported by experienced farmers. This has both advantages and challenges. On the one hand, older farmers may possess strong local knowledge of forage availability, water scarcity, animal handling, disease recognition, manure use, and traditional cattle management. On the other hand, an aging farmer population may slow the adoption of digital tools, systematic record keeping, precision livestock practices, and innovation-based management systems. It may also create succession challenges if younger generations are less interested in cattle farming. Therefore, future Madura cattle

development programs should combine support for experienced farmers with strategies to attract younger farmers through digital extension, entrepreneurship training, farmer-group business models, and market-oriented cattle development.

Table 2. Demographic and social characteristics of the respondents.

Items	Response	Number	Percentage (%)
Gender	Male	191	47.75%
	Female	209	52.25%
Age (years)	21–30	71	17.75%
	31–40	102	25.50%
	41–50	111	27.75%
	>50	116	29.00%
Occupation	Freelance	3	0.66%
	Civil Servant	29	7.24%
	Full-time cattle farmer	326	81.58%
	Self-employed	42	10.53%
Farm Location	Bangkalan	121	30.25%
	Pamekasan	94	23.50%
	Sampang	95	23.75%
	Sumenep	90	22.50%
Career length in farming (years)	1–5	109	27.25%
	6–10	8	2.00%
	11–15	77	19.25%
	16–20	54	13.50%
	21–25	68	17.00%
	>25	84	21.00%

4.2. Descriptive Analysis of Research Variables

The results of the descriptive analysis showed that all indicators in the five research constructs were in the “agree” category (Table 3). The mean value of the Resource Management indicator was in the range of 3810–3840, Technical Management in the range of 3805–3865, Environmental Management in the range of 3810–3858, Operational Efficiency in the range of 3823–3865, and Farm Performance in the range of 3825–3870. These findings show that in general, respondents have a positive perception of resource management, technical management, environmental management, operational efficiency, and farm business performance. However, all values are still in the “agree” category, so there is still room for improvement in the quality of business management to a more optimal level.

Table 3. Descriptive statistics of research indicators.

VARIABLE	INDICATOR	MEAN	SD
Resource Management	RM.01	3.833	0.737
Resource Management	RM.02	3.838	0.742
Resource Management	RM.03	3.838	0.742
Resource Management	RM.04	3.825	0.729
Resource Management	RM.05	3.835	0.739

Table 3. *Cont.*

VARIABLE	INDICATOR	MEAN	SD
Resource Management	RM.06	3.835	0.739
Resource Management	RM.07	3.818	0.752
Resource Management	RM.08	3.840	0.744
Resource Management	RM.09	3.810	0.760
Resource Management	RM.10	3.838	0.742
Technical Management	TM.01	3.853	0.757
Technical Management	TM.02	3.833	0.740
Technical Management	TM.03	3.833	0.740
Technical Management	TM.04	3.850	0.754
Technical Management	TM.05	3.805	0.709
Technical Management	TM.06	3.865	0.769
Technical Management	TM.07	3.845	0.749
Technical Management	TM.08	3.833	0.740
Technical Management	TM.09	3.840	0.747
Technical Management	TM.10	3.848	0.755
Environmental Management	EM.01	3.825	0.732
Environmental Management	EM.02	3.828	0.735
Environmental Management	EM.03	3.858	0.762
Environmental Management	EM.04	3.853	0.757
Environmental Management	EM.05	3.810	0.717
Operational Efficiency	OE.01	3.828	0.735
Operational Efficiency	OE.02	3.823	0.730
Operational Efficiency	OE.03	3.840	0.747
Operational Efficiency	OE.04	3.858	0.765
Operational Efficiency	OE.05	3.865	0.772
Operational Efficiency	OE.06	3.828	0.735
Operational Efficiency	OE.07	3.848	0.755
Operational Efficiency	OE.08	3.860	0.767
Operational Efficiency	OE.09	3.840	0.747
Operational Efficiency	OE.10	3.858	0.765
Operational Efficiency	OE.11	3.830	0.737
Operational Efficiency	OE.12	3.845	0.752
Farm Performance	FP.01	3.840	0.747
Farm Performance	FP.02	3.838	0.742
Farm Performance	FP.03	3.870	0.777
Farm Performance	FP.04	3.850	0.757
Farm Performance	FP.05	3.840	0.747
Farm Performance	FP.06	3.835	0.742
Farm Performance	FP.07	3.848	0.755
Farm Performance	FP.08	3.865	0.772
Farm Performance	FP.09	3.825	0.732

Notes: RM = Resource Management; TM = Technical Management; EM = Environmental Management; OE = Operational Efficiency; FP = Farm Performance; SD = standard deviation.

4.3. Evaluation of Measurement Models

The results of the measurement model evaluation showed that all constructs met the criteria of convergent validity and reliability (Table 4). In the Resource Management (RM) variable, the outer loading value was in the range of 0.721–0.813 with Cronbach's Alpha 0.927, Composite Reliability 0.939, and AVE 0.604. In Technical Management (TM), the outer loading value was in the range of 0.724–0.832 with Cronbach's Alpha 0.933, Composite Reliability 0.943, and AVE 0.623. Construct Environmental Management (EM) had an outer loading of 0.787–0.823, Cronbach's Alpha 0.869, Composite Reliability 0.905, and AVE 0.655. Furthermore, Operational Efficiency (OE) has an outer loading of 0.745–0.824, Cronbach's Alpha 0.945, Composite Reliability 0.952, and AVE 0.623. The Farm Performance (FP) has

an outer loading of 0.737–0.810, Cronbach’s Alpha 0.916, Composite Reliability 0.932, and AVE 0.600. Thus, all constructs can be declared valid and reliable.

Table 4. Results of convergent validity and construct reliability tests.

VARIABLE	INDICATOR	OL
Resource Management <i>CA: 0.927</i> <i>CR: 0.939</i> <i>AVE: 0.604</i>	RM.01	0.783
	RM.02	0.786
	RM.03	0.813
	RM.04	0.785
	RM.05	0.721
	RM.06	0.775
	RM.07	0.766
	RM.08	0.769
	RM.09	0.775
	RM.10	0.799
Technical Management <i>CA: 0.933</i> <i>CR: 0.943</i> <i>AVE: 0.623</i>	TM.01	0.757
	TM.02	0.828
	TM.03	0.784
	TM.04	0.724
	TM.05	0.816
	TM.06	0.832
	TM.07	0.811
	TM.08	0.765
	TM.09	0.785
	TM.10	0.787
Environmental Management <i>CA: 0.869</i> <i>CR: 0.905</i> <i>AVE: 0.655</i>	EM.01	0.787
	EM.02	0.814
	EM.03	0.803
	EM.04	0.823
	EM.05	0.820
Operational Efficiency <i>CA: 0.945</i> <i>CR: 0.952</i> <i>AVE: 0.623</i>	OE.01	0.753
	OE.02	0.776
	OE.03	0.813
	OE.04	0.768
	OE.05	0.822
	OE.06	0.745
	OE.07	0.757
	OE.08	0.820
	OE.09	0.772
	OE.10	0.821
	OE.11	0.792
	OE.12	0.824
Farm Performance <i>CA: 0.916</i> <i>CR: 0.932</i> <i>AVE: 0.600</i>	FP.01	0.737
	FP.02	0.759
	FP.03	0.786
	FP.04	0.737
	FP.05	0.794
	FP.06	0.804
	FP.07	0.767
	FP.08	0.772
	FP.09	0.810

Notes: OL=Outer Loading; CA = Cronbach’s Alpha; EM = Environmental Management; RM = Resource Management; TM = Technical Management; ; OE = Operational Efficiency; FP = Farm Performance; CR = composite reliability; AVE = average variance extracted.

Table 5 presents the discriminant validity results based on the Fornell–Larcker criterion. This test was used to ensure that each construct in the model measures a concept that is empirically distinct from the other constructs. In this study, Resource Management reflects farmers’ ability to manage land, water, feed resources, crop residues, labor, housing facilities, and capital. Technical Management reflects daily cattle husbandry practices, including feeding routines, housing/pen sanitation, animal health monitoring, disease prevention, breeding-related practices, and routine cattle care. Waste and Environmental Management reflects manure handling, waste utilization, composting, drainage, odor control, and environmental sanitation. Operational Efficiency reflects farmers’ ability to convert limited inputs into efficient daily farm operations, while Farm Performance reflects perceived production, reproduction, and economic outcomes. The diagonal values in Table 5 are higher than the correlations between constructs, indicating that the constructs are sufficiently distinct from one another.

Table 5. Discriminant validity matrix based on the Fornell–Larcker criterion.

	Resource Management	Technical Management	Environmental Management	Operational Efficiency	Farm Performance
Resource Management	0.777				
Technical Management	0.168	0.789			
Environmental Management	0.131	0.149	0.810		
Operational Efficiency	0.410	0.396	0.400	0.789	
Farm Performance	0.457	0.434	0.417	0.639	0.775

4.4. Evaluation of Structural Models

Figure 3 and Table 6 show the results of the structural model estimation using the PLS Algorithm, which shows the magnitude of the coefficient of the relationship between latent constructs in the research model. The structural model evaluation showed that the adjusted R^2 value for Operational Efficiency was 0.369, while the adjusted R^2 value for Farm Performance was 0.522. These values indicate that Resource Management, Technical Management, and Waste and Environmental Management explained 36.9% of the variance in Operational Efficiency, while Resource Management, Technical Management, Waste and Environmental Management, and Operational Efficiency explained 52.2% of the variance in Farm Performance. Thus, the model demonstrated moderate explanatory power.

However, the adjusted R^2 value of 0.369 for Operational Efficiency also indicates that approximately 63.1% of the variance in Operational Efficiency remains unexplained by the three management constructs included in the model. This suggests that Operational Efficiency among Madura cattle farmers may also be shaped by other factors not included in this study, such as herd size, land area, forage availability, water access, feed prices, market access, credit availability, institutional support, extension services, veterinary service access, farmer education, farming experience, farmer-group participation, household economic conditions, and digital record keeping. Therefore, the R^2 results should be interpreted as showing meaningful but not exhaustive explanatory adequacy.

The Q^2 predict values also support the predictive relevance of the model. The Q^2 predict value for Operational Efficiency was 0.358, and the Q^2 predict value for Farm Performance was 0.426. Because both values were greater than zero, the model can be considered to have predictive relevance for both endogenous constructs. This indicates that the model is not only statistically significant in explaining the structural relationships, but also has meaningful predictive capability for perceived Operational Efficiency and perceived Farm Performance among Madura cattle farmers.

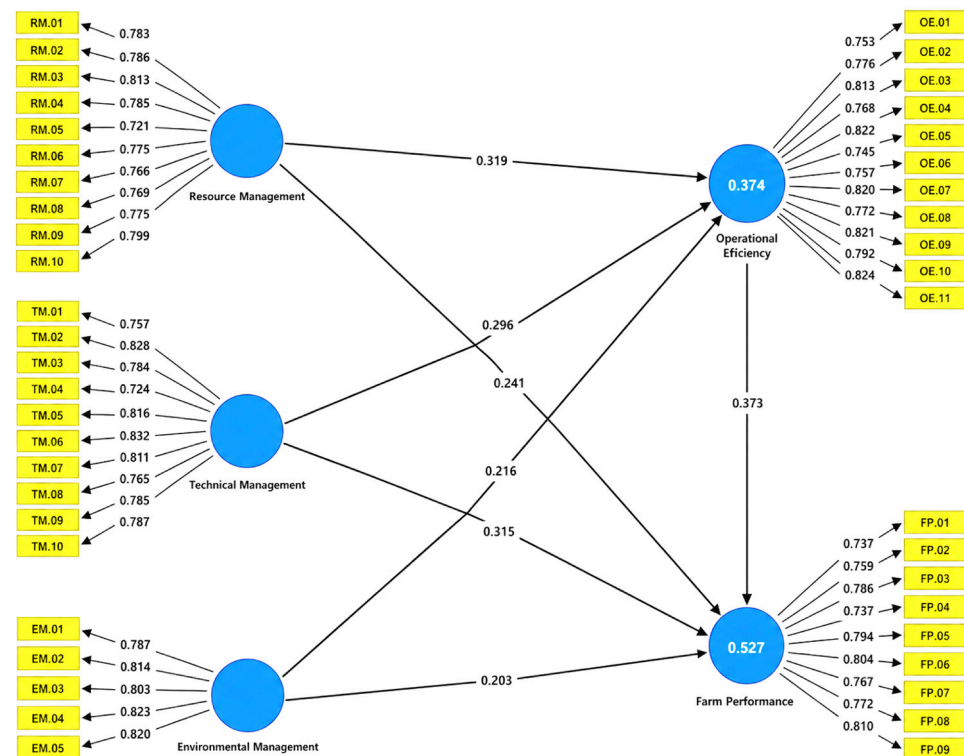


Figure 3. Structural model estimation results with PLS Algorithm. (Blue circles indicate latent constructs, yellow boxes indicate observed indicators, arrows show the direction of measurement and structural relationships, and the values on the arrows represent outer loadings or path coefficients.)

Table 6. Results of structural model evaluation.

	R-Square	R-Square Adjusted	
Operational Efficiency	0.374	0.369	
Farm Performance	0.527	0.522	
	Q ² predict	RMSE	MAE
Operational Efficiency	0.358	0.807	0.628
Farm Performance	0.426	0.761	0.620
	f-square	Remarks	
Resource Management → Operational Efficiency	0.156	Moderate	
Resource Management → Farm Performance	0.102	Weak	
Technical Management → Operational Efficiency	0.134	Weak	
Technical Management → Farm Performance	0.083	Weak	
Environmental Management → Operational Efficiency	0.153	Moderate	
Environmental Management → Farm Performance	0.073	Weak	
Operational Efficiency → Farm Performance	0.185	Moderate	

The f^2 values provide information about the practical contribution of each predictor to the endogenous constructs. In this study, the effects of Resource Management on Operational Efficiency ($f^2 = 0.156$), Waste and Environmental Management on Operational

Efficiency ($f^2 = 0.153$), and Operational Efficiency on Farm Performance ($f^2 = 0.185$) were categorized as moderate effects. These results indicate that these relationships have meaningful practical importance in explaining farm efficiency and performance. Meanwhile, the remaining paths were categorized as weak effects, meaning that each predictor still contributes to the endogenous construct, but its individual contribution is relatively limited and should be strengthened through integrated management interventions. Therefore, weak effects should not be interpreted as unimportant, but rather as evidence that farm performance in Madura smallholder cattle systems is shaped by multiple interrelated management factors.

4.5. Hypothesis Testing

The bootstrapping results show that all research hypotheses are supported (Table 7 and Figure 4). Resource Management has a positive and significant effect on Operational Efficiency ($\beta = 0.319$; $t = 8.738$; $p < 0.001$), Technical Management has a positive and significant effect on Operational Efficiency ($\beta = 0.296$; $t = 6.618$; $p < 0.001$), and Environmental Management also has a positive and significant effect on Operational Efficiency ($\beta = 0.315$; $t = 7.062$; $p < 0.001$). Furthermore, Operational Efficiency has a positive and significant effect on Farm Performance ($\beta = 0.373$; $t = 8.773$; $p < 0.001$). In addition, Resource Management ($\beta = 0.241$; $t = 6.345$; $p < 0.001$), Technical Management ($\beta = 0.216$; $t = 5.675$; $p < 0.001$), and Environmental Management ($\beta = 0.203$; $t = 5.196$; $p < 0.001$) also had a positive and significant effect directly on Farm Performance.

Table 7. Direct, indirect, and total effects.

Relationship	Direct Effect β	t-Value	p-Value	Indirect Effect via OE β	t-Value	p-Value	Total Effect β	Decision
Resource Management → Operational Efficiency	0.319	8.738	<0.001	—	—	—	0.319	Supported
Technical Management → Operational Efficiency	0.296	6.618	<0.001	—	—	—	0.296	Supported
Waste and Environmental Management → Operational Efficiency	0.315	7.062	<0.001	—	—	—	0.315	Supported
Operational Efficiency → Farm Performance	0.373	8.773	<0.001	—	—	—	0.373	Supported
Resource Management → Farm Performance	0.241	6.345	<0.001	0.119	6.312	<0.001	0.360	Supported; partial mediation
Technical Management → Farm Performance	0.216	5.675	<0.001	0.110	5.177	<0.001	0.326	Supported; partial mediation
Waste and Environmental Management → Farm Performance	0.203	5.196	<0.001	0.118	5.294	<0.001	0.321	Supported; partial mediation

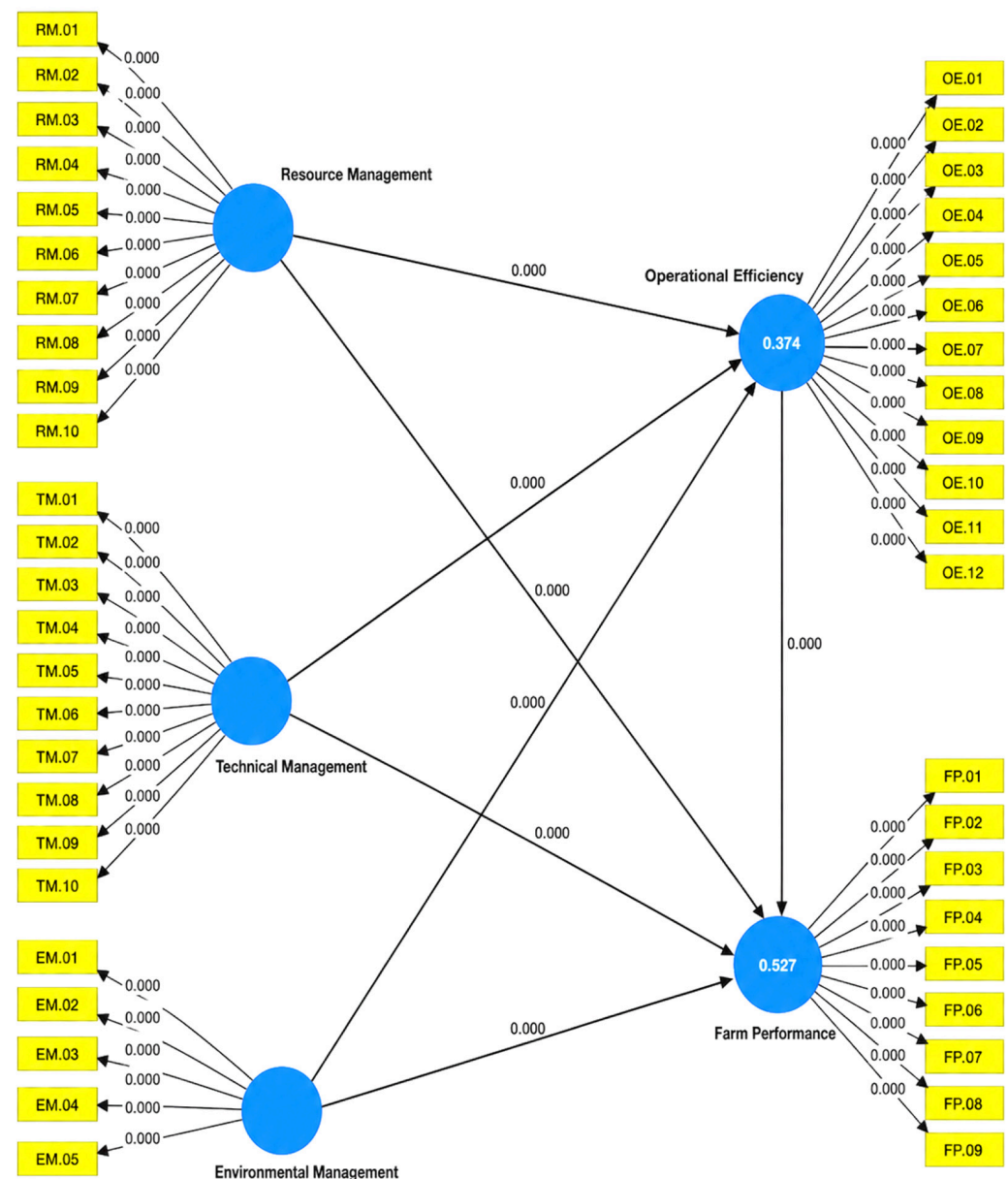


Figure 4. Results of the research model bootstrapping.

In the indirect influence, Resource Management has a positive and significant effect on Farm Performance through Operational Efficiency ($\beta = 0.119$; $t = 6.312$; $p < 0.001$), Technical Management has a positive and significant effect on Farm Performance through Operational Efficiency ($\beta = 0.110$; $t = 5.177$; $p < 0.001$), and Environmental Management has a positive and significant effect on Farm Performance through Operational Efficiency ($\beta = 0.118$; $t = 5.294$; $p < 0.001$). Since the direct and indirect influences are all equally significant, Operational Efficiency can be interpreted as a partial mediator in this model. This interpretation shows that Farm Performance is influenced both directly by managerial practices and indirectly through increased operational efficiency.

The mediation analysis was further assessed using the Variance Accounted For (VAF) statistic. VAF was calculated by dividing the indirect effect by the total effect. The VAF value for the Resource Management $\rightarrow$ Operational Efficiency $\rightarrow$ Farm Performance pathway was 33.1%, indicating that approximately one-third of the total relationship between Resource Management and Farm Performance was transmitted through Operational Efficiency. The VAF value for the Technical Management $\rightarrow$ Operational Efficiency $\rightarrow$ Farm Performance

pathway was 33.7%, while the VAF value for the Waste and Environmental Management → Operational Efficiency → Farm Performance pathway was 36.8%. Because all VAF values were between 20% and 80%, the results indicate partial mediation. This means that Operational Efficiency explains a meaningful proportion of the relationships between management practices and Farm Performance, while the direct relationships between the management constructs and Farm Performance remain significant.

5. Discussion

5.1. The Influence of Resource Management on Operational Efficiency and Farm Performance

The results of the study show that Resource Management has a positive and significant effect on Operational Efficiency and Farm Performance. These findings confirm that the management of basic business resources, such as land, water, and adaptation to climate, is an important foundation for the success of Madura cattle farming. In the context of smallholder farming, proper land management helps the availability of forage and cage layout, while the availability of clean water and adjustment to climatic conditions support the smooth running of maintenance activities. These results are in line with the research of Nyawira, Mwendia, Mwema, Gonzalez-Quintero, Nzogela, Sila, Mwilawa, Kizima, Paul and Notenbaert [17] which showed that the adoption of improved forage cultivation plays an important role in increasing biomass production, dairy yield, and soil health in small farm systems, as well as with agroecological studies in Peru which show that the type of business system and agroecological management are closely related to the performance of small farm systems. Studies on Madura cattle show that this breed is commonly managed under smallholder farming conditions, where farmers rely heavily on locally available feed resources, crop residues, family labor, and simple housing facilities [35,36]. Research on the reproductive performance of Madura cattle under farmers' management conditions also indicates that farm-level management practices, particularly nutrition and farmer management, are important for supporting reproductive outcomes [35]. Similarly, studies on Madura cattle in Bangkalan highlight the role of local feed resources in optimizing cattle performance in smallholder farms [36]. These findings support the present study's argument that effective management of feed, water, land, labor, housing facilities, and other farm resources is central to improving Operational Efficiency and Farm Performance among Madura cattle farmers.

The result is also consistent with recent Indonesian smallholder cattle literature, which emphasizes that sustainable beef cattle development depends on integrated management of feed resources, farmer livelihoods, animal health, and economic conditions [37]. In the Madura context, cattle–crop integration is particularly relevant because crop residues can be used as feed, while manure can be returned to cropland as organic fertilizer. Recent evidence on the Madura cattle–field crop integration system shows that cattle maintenance and field-crop management contribute to increasing farmer income [14]. Therefore, Resource Management in Madura cattle farming should not be interpreted only as the availability of inputs, but as the farmer's ability to allocate and recycle limited resources within a dryland, household-based, and integrated cattle–crop production system.

Substantively, the influence of Resource Management on Operational Efficiency ($\beta = 0.319$) is slightly higher than the influence of Technical Management, and the effect is in the moderate category. This shows that resource management is not just a supporting factor, but a strategic component that allows farmers to minimize waste and use inputs more rationally. These findings are also consistent with the study of the One Health-based smallholder cattle farming system which emphasizes that business output is simultaneously influenced by production conditions, nutrition, disease, and access to supporting facilities [1].

5.2. *The Influence of Technical Management on Operational Efficiency and Farm Performance*

This study shows that Technical Management has a positive and significant effect on Operational Efficiency and Farm Performance. These findings confirm that daily maintenance practices, such as cage cleanliness, livestock health monitoring, disease control, and feed management, are the main determinants of well-organized and uninterrupted daily cattle-farming activities and business results. In smallholder cattle farms, good technical management allows livestock to grow healthier, reduces the risk of production disruptions, and increases the effectiveness of feed use and labor. These results are in line with research by Were, Okumu and Kimeli [18] in Kenya which showed that feeding practices, livestock body conditions, and disease status such as mastitis are significantly related to daily milk yield on small farms. These findings are also in line with Kitole [23] study which shows that extension and knowledge transfer programs encourage the adoption of better practices and increase the production and income of small farmers.

Although the value of the Technical Management coefficient on Farm Performance ($\beta = 0.216$) is lower than that of Resource Management, this pathway is still significant and confirms that the quality of forage and crop–livestock management practices is a lever for business performance. Practically, these results show that improving feed quality, simple biosecurity, and regular livestock health checks can be very relevant intervention points for Madura cattle farmers. The reference to Heerden, Grobbelaar, Meyer and Vermeulen [1] was retained only as a general example showing that disease management and technical husbandry are important components of smallholder cattle-system dynamics. However, the interpretation of the present findings was revised to rely primarily on Indonesian smallholder beef cattle literature because the production environment, institutional setting, and disease-management context in Madura differ from those in South Africa.

5.3. *The Influence of Environmental Management on Operational Efficiency and Farm Performance*

The results of the study show that Environmental Management has a positive and significant effect on Operational Efficiency and Farm Performance. These findings are important because they show that livestock waste management is not only an environmental issue, but also part of a strategy to improve business efficiency and performance. In this study, livestock waste management refers to the farm-level collection, storage, processing, and utilization of manure, urine, leftover feed, bedding residues, wastewater, and other cattle-related organic waste. It includes regular manure collection, proper manure storage, composting, organic fertilizer production, drainage management, odor control, wastewater handling, and biogas utilization where feasible. In Madura cattle farms, well-managed waste can reduce pollution, maintain cage cleanliness, and open opportunities for economic utilization, for example as fertilizer. These results are in line with the study of Qu, Groot and Zhang [20] which showed that improved waste management can reduce nitrogen loss by 46–58% and increase the efficiency of nitrogen use in farming systems. These results are also in line with Simamora, Tahuk, Rofiq, Matoneng, Sio, Risman Dwi Jumansyah, Correia and Correia [8] research on beef cattle farms in dry regions of Indonesia, which shows that the ease of innovation such as cow feces processing technology has a significant effect on business sustainability.

Interestingly, the influence of Environmental Management on Operational Efficiency ($\beta = 0.315$) is almost equivalent to that of Resource Management. This suggests that environmental management should no longer be placed as an additional component, but as an integral part of livestock business management. Waste and Environmental Management in this study includes waste utilization, nutrient loss reduction, and sanitation practices. Waste utilization refers to the productive use of manure, urine, leftover feed, bedding residues, and wastewater through composting, organic fertilizer production, and

biogas utilization where feasible. Nutrient loss reduction refers to practices that minimize the loss of nitrogen, phosphorus, potassium, and organic matter from livestock waste through proper collection, storage, composting, and use of manure or compost on cropland. Sanitation refers to routine cleaning and maintenance of cattle housing, drainage channels, feeding areas, drinking-water facilities, and waste-handling areas to reduce odor, disease risk, wastewater accumulation, and environmental pollution. In Madura smallholder cattle farming, these practices are important because they help maintain housing hygiene, improve resource recycling, support soil fertility, and strengthen cattle–crop integration [38].

5.4. Comparative Effects of Management Dimensions on Operational Efficiency

The relatively similar effects of Resource Management ($\beta = 0.319$), Technical Management ($\beta = 0.296$), and Waste and Environmental Management ($\beta = 0.315$) on Operational Efficiency indicate that no single management dimension dominates efficiency formation in Madura cattle farming. This can be explained by Madura's dry climate and fragmented smallholder production structure. Resource Management matters because farmers must carefully allocate limited land, water, local feed resources, crop residues, labor, and capital under seasonal forage scarcity. Technical Management is similarly important because small household-based farms depend on daily husbandry practices, such as feeding, housing/pen management, animal health monitoring, and disease prevention, to reduce production disruptions. Waste and Environmental Management also has a comparable effect because manure handling, sanitation, drainage, and waste utilization directly affect housing cleanliness, animal health, labor use, and cattle–crop integration. Therefore, operational efficiency in this context is best understood as the result of integrated resource, technical, and waste/environmental management rather than the effect of one isolated managerial practice.

5.5. The Effect of Operational Efficiency on Farm Performance

The findings of the study show that Operational Efficiency has a positive and significant effect on Farm Performance, with the largest path coefficient in the model ($\beta = 0.373$). The strongest path coefficient in the model was the effect of Operational Efficiency on Farm Performance ($\beta = 0.373$), indicating that efficiency is the core mechanism linking management practices with production, reproduction, and economic outcomes. In Madura's dryland and low-input smallholder system, farmers operate under constraints such as seasonal forage scarcity, limited water availability, restricted capital, small herd size, and dependence on family labor. Under these conditions, farm performance depends not only on the availability of resources or technical practices, but also on how efficiently farmers convert inputs such as local feed resources, crop residues, water, labor, housing facilities, veterinary inputs, breeding services, manure, and operating capital into productive outputs.

This finding highlights the importance of input–output optimization and context-appropriate precision farming. For Madura cattle farmers, precision farming can begin with simple monitoring practices, including records of feed use, body condition, reproductive events, animal health, labor use, production costs, manure utilization, and sales or income. Such records can help farmers and extension officers identify inefficiencies, improve feed planning, reduce waste, strengthen reproductive management, control costs, and optimize resource use. Therefore, development programs should prioritize efficiency-oriented interventions rather than merely increasing input quantity.

These findings are in line with the study of Nsabiyeze, Zhang, Li, Zhao and Zhang [19] which affirm that monitoring and *decision support* systems in modern farms can improve efficiency, reduce emissions, and improve animal welfare. In addition, Ariningsih, Erwidodo,

Saliem, Purwantini, Anugrah, Irawan, Sumaryanto, Priyono, Inayah and Purba [22] conducted in East Java, Indonesia, emphasizes that improving technical efficiency in smallholder farms is essential for increasing productivity and supporting long-term sustainability. Thus, operational efficiency in this study can be seen as a core managerial capacity that connects business practices with production, reproduction, and economic outcomes [39].

5.6. *The Role of Operational Efficiency Mediation*

One of the main contributions of this study is the evidence that Operational Efficiency significantly mediates the relationship between Resource Management, Technical Management, and Environmental Management on Farm Performance. Because the direct and indirect influences are all significant, the form of mediation that occurs is partial mediation. These findings mean that these three management dimensions not only have a direct effect on business performance but also work through improving operational efficiency. In other words, good resource management, technical practices, and environmental management first facilitate business operations, reduce waste, and improve the use of inputs, before finally being reflected in improving business performance.

Empirically, the indirect influence of Resource Management through Operational Efficiency is 0.119, Environmental Management is 0.118, and Technical Management is 0.110. These relatively close values show that these three management dimensions showed numerically comparable indirect effects through Operational Efficiency, indicating that each contributes meaningfully to efficiency-based Farm Performance improvement. However, because no formal statistical comparison of the indirect effects was conducted, the results should not be interpreted as evidence that the three management dimensions are statistically equal in importance. These results are consistent with the latest literature that shows that more integrated, more efficient, and more adaptive livestock systems tend to have better and more sustainable business outcomes [40,41]. Thus, the Madura cattle farm development strategy should not only focus on one dimension, but on the simultaneous improvement of resource, technical, and environmental aspects, with operational efficiency as the main connecting mechanism.

5.7. *Theoretical and Practical Implications*

Theoretically, this study extends the Resource-Based View by showing that resources in Madura smallholder cattle farming become valuable when farmers can organize and convert them into efficient farm operations. Land, water, local forage, crop residues, labor, cattle housing facilities, manure, and capital do not automatically improve Farm Performance unless they are managed efficiently. Operational Efficiency therefore functions as a conversion mechanism between resource ownership, management practices, and perceived production, reproduction, and economic outcomes. The findings also support the Dynamic Capabilities framework because Madura cattle farmers must continuously adapt feed use, water management, technical husbandry, animal health practices, and waste handling under dryland, low-input, and fragmented smallholder conditions.

Practically, the findings suggest that extension workers, government programs, and farmer groups in Madura should prioritize concrete efficiency-oriented interventions. Resource Management interventions should include forage planning, crop-residue utilization, dry-season feed banks, community water storage, rainwater harvesting where feasible, and better use of limited land for forage and cattle–crop integration. Technical Management interventions should include mobile veterinary services, disease-prevention training, housing/pen sanitation, reproductive recording, body condition observation, deworming, vaccination or veterinary consultation when needed, and improved feeding routines. Waste and Environmental Management interventions should include manure composting, or-

ganic fertilizer production, improved drainage, odor control, and biogas utilization where feasible. Farmer cooperatives can support these efforts through shared feed banks, collective input purchasing, cooperative marketing, group-based composting or biogas units, and simple farm record-keeping systems. These interventions can help farmers improve Operational Efficiency and strengthen production, reproductive continuity, income, and environmental sustainability [17].

6. Conclusions

This study contributes to the literature on sustainable smallholder cattle farming by developing and testing an integrated management model for Madura cattle farmers. The findings show that Resource Management, Technical Management, and Waste and Environmental Management influence production, reproduction, and economic Farm Performance both directly and indirectly through Operational Efficiency. This suggests that Madura cattle farming performance should not be understood merely as a function of production inputs or herd ownership, but also as the result of farmers' ability to organize resources, apply appropriate husbandry practices, manage manure and farm waste, and convert limited inputs into efficient farm operations. The mediating role of Operational Efficiency represents the main conceptual contribution of this study, indicating that management practices become more valuable when they improve the allocation and use of land, water, local feed resources, crop residues, labor, cattle housing facilities, veterinary inputs, breeding services, manure, and operating capital. In the dryland and low-input context of Madura cattle farming, this mechanism is particularly important because farmers often face seasonal forage scarcity, limited water availability, restricted capital, and dependence on family labor.

From a practical perspective, the findings imply that Madura cattle development programs should not focus only on increasing cattle numbers or providing isolated technical assistance. Instead, these programs should prioritize concrete and locally feasible interventions. Resource Management should focus on forage planning, crop-residue utilization, dry-season feed reserves, water storage, efficient drinking-water management, and better use of limited land for forage production, cattle housing, and cattle-crop integration. Technical Management should emphasize feeding routines, housing/pen sanitation, animal health monitoring, disease prevention, reproductive recording, and body condition observation. Waste and Environmental Management should focus on regular manure collection, composting, organic fertilizer production, improved drainage, odor control, and biogas utilization where feasible. Local governments, livestock extension officers, and farmer groups should strengthen farmers' capacity in these areas because such interventions can improve operational efficiency while strengthening production, reproductive continuity, income, and environmental sustainability. These efforts may also support the conservation and sustainable use of Madura cattle as an indigenous Indonesian livestock genetic resource.

This study has several limitations that should be acknowledged. First, the cross-sectional design limits the ability to draw strong causal conclusions because all variables were measured at one point in time. Second, all constructs were measured using farmers' self-reported perceptions through Likert-scale indicators; therefore, the findings should be interpreted as perceived Resource Management, Technical Management, Waste and Environmental Management, Operational Efficiency, and Farm Performance rather than as direct objective measurements. Third, the study did not include objective farm records such as herd size changes, calving interval, pregnancy rate, mortality rate, body weight gain, feed conversion, production costs, net income, or manure output. Fourth, the study was conducted only on Madura Island, so the findings may not be directly generalizable to other cattle breeds, islands, or production systems. Fifth, because the independent vari-

ables, mediator, and dependent variable were collected from the same respondents using the same questionnaire, potential common method bias cannot be fully excluded. Future research should address these limitations by using longitudinal or panel designs, combining perception-based survey data with objective production, reproduction, economic, and environmental records, and conducting comparative studies across different Indonesian local cattle breeds and regions. Future models should also incorporate additional explanatory factors such as herd size, market access, feed prices, institutional support, extension services, technology adoption, farmer organization, and broader environmental indicators, including water use, nutrient cycling, greenhouse gas emissions, and land-use pressure.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/resources15070088/s1>, Table S1.

Author Contributions: A.S.: Conceptualization, Funding acquisition, Methodology, Writing—original draft, Supervision. I.I.: Data curation, Formal analysis, Writing—review & editing. R.H.: Resources, Investigation. M.P.G.: Methodology, Investigation, Writing—review & editing. A.F.: Formal analysis. Y.A.C.E.: Software, Validation. S.A.A.: Project administration, Visualization, Writing—review & editing. I.O.D.: Formal analysis, Data curation. Investigation, Writing—review & editing. Z.M.: Project administration, Software. Z.Z.N.W.: Methodology, Investigation, Muhammad I.W.: Visualization, Data Curation. M.I.W.: Methodology, Formal analysis, Investigation. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: This study was conducted in accordance with applicable ethical standards for social and humanities research. The study was reviewed and approved by the Social Humanities Research Ethics Committee of Universitas Islam Madura under approval number 121/LPPM-UIM/I/2026, approved on 11 January 2026.

Informed Consent Statement: Prior to data collection, all respondents were informed about the purpose of the study, the voluntary nature of their participation, and the confidentiality of their responses. Informed consent was obtained from all respondents before the interviews were conducted.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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