Research Article

Adaptive Capacity of Beef Cattle Farmers in Dryland Border Areas of Indonesia–Timor Leste

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Abstract | This present study investigates the adaptive ability of beef cattle producers in Indonesia–Timor Leste dry climate border zone using the influence of social and human resources variables (X1), economic resilience (X2), and environmental carrying capacity (X3). The research locations were in Timor Tengah Utara and Belu Regencies. The research method used was a mixed method. With a quantitative approach based on PLS-SEM and complemented by qualitative field data, the result of the analysis verifies that social and human resources, economic resilience, and environmental carrying capacity lie mainly in the moderate category, with parts of the environment falling in the low category. In addition, adaptive capacity (Y1) is moderate. PLS-SEM analysis further confirms that X1, X2, and X3 significantly affect adaptive capacity ($p < 0.05$) with an R^2 of 0.660, showing that 66% of the variance is explained in the model. Analysis of qualitative data demonstrates that adaptive capacity is enhanced through tradition-based social capital, household economic diversification, and locally adaptive resource management. The originality of the research lies in its integration of quantitative and qualitative approaches used in the arid border context to offer a new layer in methods towards driving adaptation and sustaining beef cattle production.

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Introduction

Beef cattle raising is at the very heart of livelihoods in most arid regions of the world, and more particularly along border areas where clusters of vulnerabilities-environmental, economic, and institutional often occur. Rainfall irregularity and prolonged dry season characterize ecosystems within the Indonesia–Timor Leste border area with naturally limited resources exacerbated by increasing pressure due to land conversion (Simamora *et al.*, 2024). Such constraints emphasize production-oriented skills for farmers but add a requirement for adaptive capacities; that is, the ability to adjust strategies through accessing new information channels, diversifying sources of income, and

managing ecological risks. Where such adaptive capacity does not exist, environmental degradation precipitates poverty in livestock-based livelihood systems besides other socio-economic shocks.

Social and human resources—education, technical knowledge, social relations, individual confidence, information access, and partnership ability—are major factors in determining adaptive capacity (Chisale *et al.*, 2024). Empirical evidence has indicated that cattle farmers require higher education, training, and increased social capital to implement improved feeding practices and drought management successfully in response to climate change proactively; these are adjustments related to ameliorating the impacts of climate change (Stringer *et al.*, 2022). Some of the findings from research on smallholder farmers in Ghana indicated that awareness, training, economic resources, and institutional access were some of the determinants significantly influencing adaptive capacity (Abdul-Razak and Kruse, 2017). Other studies on the impact of climate change on livestock systems found these as gaps between adaptation policies and strategies because such policies did not sufficiently cover human and social resource dimensions (e.g. knowledge and adaptation strategies) (Escarcha *et al.*, 2018).

Besides human and social capital, economic resilience counts. This involves steady and adequate income from livestock, ease of investment or credit access, diversification of livelihoods, productivity, and cost management as well as capacity in coping with market pressure and price changes. The economic resilience of livestock farmers is a strong economy that justifies similar adaptability towards such like systems of dryland farming. The economic resilience depicted in this paper is limited to economic performance and market access for inputs and outputs rather than other factors even after the COVID-19 pandemic (Benu *et al.*, 2024).

Carrying capacity is, also, a major factor in supporting natural resource base and ecosystem services for the environmental beef cattle farm. This carrying capacity includes several factors such as land availability and quality, the availability of feed, waste management, and mitigation in negative impacts on the environment together with climate change mitigation measures (Zandler *et al.*, 2023; Morshed *et al.*, 2024). Based on literature studies, constraints in beef cattle farming are usually limited quantity and quality of feed and sustainability of feed availability especially during the dry season-in addition to land degradation plus challenges in waste management-as well as climate impacts (temperature, rainfall variability) which impose great limitations on productivity and sustainability (Henry *et al.*, 2018). Results from this study have indicated that factors like feed quality and quantity together with degradation of the grazing pastures are high vulnerability factors in tropical livestock systems. Therefore, adaptation policies and strategies are highly required to address such issues (Cheng *et al.*, 2022).

It is advisable to review the joint effect of social and human resources, economic resilience, and environmental support on the adaptive capacity of beef cattle households in the dry climates of Indonesia and Timor Leste's border region. Understanding these effects can help spot where policy interventions, technical assistance, extension efforts and institutional support should aim (e.g., improving access to finance, building social networks, setting up environmental resource management). By tackling this empirical hole in this specific border setup, the study can help both locally with livelihood and sustainability and more broadly with adaptation theory and practice in dryland livestock systems.

Materials and Methods

This study took place in Timor Tengah Utara and Belu Regencies, East Nusa Tenggara from June to August 2025 with the use of a structured questionnaire survey. The number of respondents taken in each regency was 250 people, so the total number of respondents was 500 people used in this study who implemented beef cattle farming. Subjects have been purposively selected with major criteria having at least three years of continuous and regular practice on beef cattle farming while being a permanent resident within the research location and participation in any group or activity related to livestock. (Etikan, 2016).

The scale employed for data measurement is a Likert scale with four major variables. Social and human resource factors (X1) include education and experience (X1.1), access to information and technology (X1.2), social networks and livestock groups (X1.3), business adaptability (X1.4), and farmer confidence and independence (X1.5). The construct of economic

resilience (X2) has the following dimensions: income from the livestock business (X2.1); access to capital and investment (X2.2); diversification of the business (X2.3); efficiency in production and costs (X2.4); and economic risk resilience variables (X2.5). The concept variable of environmental carrying capacity (X3) comprises land and natural resource utilization (X3.1); feed availability, quality (X3.2); livestock waste management (X3.3); the environmental impact of livestock businesses(X3 .4) and climate change mitigation(X3.5). The adaptation capacity variable (Y1) is described by the environmental and climate adaptation capacity (Y1.1), a non-livestock income (Y1.2), information and innovation access-ability easiness (Y1.3), partnership building and adaptation strategy implementation ability (Y1.4), and business operation maintaining ability (Y1.5).

Descriptive and inferential analysis were used. Descriptive analysis was used to state the characteristics of the population of beef cattle farmers and the distribution of variables in percentage terms, which means describing the socio-economic and environmental conditions of respondents. Inferential analysis used the smartPLS 4 application based on the PLS-SEM approach. This approach was used to test the influence of social and human resources variables (X1), economic resilience (X2), and environmental carrying capacity (X3) on adaptive capacity (Y1). This model was employed to test path coefficients from social and human resources variables (X1), economic resilience (X2), and environmental carrying capacity (X3) to adaptive capacity (Y1). Some benefits accrue mainly because this software has an express capacity for dealing with rather intricate models involving several constructs together with a not so large sample size (Hair *et al*., 2017). The model appraisal comprises an assessment of validity and reliability by means of bootstrapping to analyze the hypothesized link (Hair *et al*., 2021). This study is supposed to give a detailed account of how social, economic, and environmental factors determine the adaptive capacity of beef cattle farmers in dry border areas. At the same time, it is supposed to inform on these factors as well as generate data for policymakers to use when creating interventions aimed at strengthening livestock-based livelihoods in drylands.

Results and Discussion

Social factors and human resources (X1)

Descriptive analysis of the Social and Human Resource Factors variable (X1) shows that the dominant aspect remains in the moderate category. The results of this study indicate that the basic capacity of farmers to manage cattle farming businesses in the dry border region between Indonesia and Timor Leste is still inadequate.

Table 1: *Level of social factors and human resources (x1)*

Variable	Categories	Frequency (people)	Percentage (%)
X1.1	Very low	32	6.4
	Low	80	16
	Moderate	296	59.2
	High	92	18.4
X1.2	Very low	22	4.4
	Low	84	16.8
	Moderate	352	70.4
	High	42	8.4
X1.3	Very low	27	5.4
	Low	96	19.2
	Moderate	344	68.8
	High	33	6.6
X1.4	Very low	17	3.4
	Low	94	18.8
	Moderate	340	68
	High	49	9.8
X1.5	Very low	18	3.6
	Low	77	15.4
	Moderate	340	68
	High	65	13

The analysis of social and human resource factors (X1) among beef cattle farmers in the Indonesia–Timor Leste border area demonstrates that the majority of indicators fall into the moderate category. The sub-variable of education and experience (X1.1) attained a percentage of 59.2%, indicative of minimal formal education (predominantly primary and lower secondary) and a reliance on traditional knowledge. The sub-variable of access to information and technology (X1.2) attained a score of 70.4%, indicating that although farmers do occasionally receive information from extension workers, social media, or group forums, weak communication infrastructure and low digital literacy hinder effective adoption of innovations (Coggins *et al*., 2022).

The sub-variable of social networks and livestock groups (X1.3) scored 68.8%, indicating that while

social ties are relatively robust, these groups function more as social forums than as instruments of economic empowerment and technology transfer. The sub-variable of business adaptability (X1.4) attained a score of 68%, with farmers demonstrating a capacity to adjust through grazing management, utilisation of local feed, and crop-livestock integration. However, their strategies are predominantly reactive rather than proactive. The results of this study explain the importance of strengthening adaptive institutional strategies as a long-term business practice.

Table 2: *Level of economic resilience (X2)*

Variable	Categories	Frequency (people)	Percentage (%)
X2.1	Very low	18	3.6
	Low	136	27.2
	Moderate	317	63.4
	High	29	5.8
X2.2	Very low	29	5.8
	Low	127	25.4
	Moderate	320	64
	High	24	4.8
X2.3	Very low	40	8
	Low	243	48.6
	Moderate	196	39.2
	High	21	4.2
X2.4	Very low	14	2.8
	Low	138	27.6
	Moderate	322	64.4
	High	26	5.2
X2.5	Very low	44	8.8
	Low	226	45.2
	Moderate	210	42
	High	20	4
	Total	500	100

Farmer confidence and independence (X1.5) rated 68% meaning that beef cattle farmers have confidence and motivation toward the development of their livestock business, but confidence is on the wane because of economic pressure and so much dependence on government assistance. The measurement results are also in the moderate category for these indicators, a condition that prescribes that it is imperative to apply an improvement and enhancement measure regarding the independence of beef cattle farmers. Such measures may include strengthening participatory extension service, digital literacy, livestock group empowerment, and economic independence (Managanta, 2020).

Economic resilience (X2)

The results of the descriptive analysis of the Economic Resilience variable (X2) explain that most indicators are in the moderate category. However, there are still elements that remain in the low category.

The analysis of economic resilience (X2) demonstrates that several sub-variables fall into the moderate category, while some remain low. The sub-variable of livestock business income (X2.1) scored 63.4%, indicating that beef cattle farming contributes significantly to household economies but is often treated as a long-term savings rather than a stable daily income source (Liu *et al.*, 2023). In a similar manner, the dimension of access to capital and investment (X2.2) attained a score of 64%. The majority of farmers depend on personal savings or family loans as their primary source of financial support for larger investments. However, limited access to formal credit opportunities and cumbersome bureaucratic processes impede the capacity for such investments to be made on a larger scale . This condition imposes limitations on the potential for enhancement in the domains of barns, feed provision, and technological adoption (Balana and Oyeyemi, 2022; Ma *et al.*, 2024).

The sub-variable of business diversification (X2.3) obtained a low score of 48.6%, indicating that the majority of households are dependent on cattle farming alone, with no development of alternative businesses such as horticulture or trade. This reliance accentuates exposure to market volatilities and livestock diseases. Meanwhile, production and cost efficiency (X2.4) attained a moderate score of 64.4%, with feed constituting the most substantial expense, particularly during the dry season. It is evident that farmers continue to depend on natural forage, with minimal utilisation of alternative feed technologies. However, it is noteworthy that certain collective group initiatives have been initiated for the management of feed, albeit on a modest scale.

The indicator with the lowest performance was resilience to economic risks (X2.5), which received a low score of 45.2%. Farmers continue to experience significant vulnerability in the face of price fluctuations, livestock health concerns, and drought conditions. The findings of this study are consistent with the

conclusions of previous research which indicates that livestock businesses are significantly impacted by price volatility and the risk of drought (Made and Made, 2021). This vulnerability often leads to the sale of cattle at reduced prices during times of crisis, primarily due to the absence of insurance and effective risk mitigation strategies. The findings indicate that, while livestock income possesses strategic value, the absence of diversification, constrained access to finance, and ineffective risk management compromise economic resilience. In order to enhance resilience and support long-term sustainability, it is imperative to take the following measures: first, to strengthen financial literacy; second, to improve access to capital; third, to encourage diversification; and fourth, to introduce livestock insurance.

Environmental carrying capacity level (X3)

A descriptive analysis of the Environmental Carrying Capacity variable (X3) reveals variations in conditions, with a predominant tendency towards the moderate category, although certain aspects remain classified as low.

Table 3: *Environmental carrying capacity level (X3)*

Variable	Categories	Frequency (people)	Percentage (%)
X3.1	Very low	122	24.4
	Low	255	51
	Moderate	106	21.2
	High	17	3.4
X3.2	Very low	24	4.8
	Low	193	38.6
	Moderate	265	53
	High	18	3.6
X3.3	Very low	38	7.6
	Low	199	39.8
	Moderate	249	49.8
	High	14	2.8
X3.4	Very low	18	3.6
	Low	138	27.6
	Moderate	326	65.2
	High	18	3.6
X3.5	Very low	13	2.6
	Low	141	28.2
	Moderate	321	64.2
	High	25	5
	Total	500	100

The analysis of environmental carrying capacity (X3) reveals several weaknesses alongside moderate progress. The sub-variable of land and natural resource utilisation (X3.1) attained a low score of 51%, indicating that grazing land is becoming increasingly constrained due to land conversion and that conventional land management practices impede the optimal utilisation of natural resources such as local fodder crops. In a similar vein, the sub-variable of feed availability and quality (X3.2), at 53%, signifies that, while feed requirements are generally met, shortages during the dry season and reliance on low-nutrient alternatives such as straw and leaves impede productivity and sustainability (Simamora *et al.*, 2025).

The sub-variable of livestock waste management (X3.3) was recorded at 49.8%, reflecting limited efforts where manure is mostly left to accumulate or used directly as fertiliser, with only a few farmers processing it into compost or biogas. The findings of this study are corroborated by research Riptanti *et al.* (2021) indicating an augmentation in the sustainable status of dryland farming management in the future. Consequently, there is a necessity to implement a strategy for utilising livestock waste. Conversely, the environmental impact of livestock farming (X3.4) was moderately scored at 65.2%, indicating that farmers are cognisant of the adverse effects, including odours and water contamination, and have adopted rudimentary measures such as pen cleaning and manure storage relocation. However, these measures remain unadvanced and lack innovation.

The sub-variable of climate change mitigation (X3.5) scored 64.2%, indicating that farmers are cognisant of the impacts of prolonged dry seasons and erratic rainfall, and endeavour to implement straightforward measures such as adjusting grazing schedules and storing feed during the rainy season. This assertion is further substantiated by (Vignal *et al.*, 2023) the observation that livestock systems in arid regions exhibit enhanced resilience when livestock destocking rates are adapted to variations in forage availability. These practices remain rooted in tradition, devoid of scientific or technological underpinnings. The findings indicate the presence of environmental awareness; however, limitations in land use, feed technology, waste management, and climate mitigation restrict the sustainability of cattle farming. The enhancement of innovative feed solutions, the establishment

of circular waste management systems, and the provision of climate-focused technical assistance are of paramount importance in the enhancement of adaptive capacity and long-term resilience in dryland border regions (Simamora *et al*., 2024).

Adaptive capacity (Y1)

A descriptive analysis of the adaptive capacity variable (Y1) reveals that all sub-variables are classified as moderate, exhibiting significant percentage variations. This finding suggests that beef cattle farmers in the Indonesia–Timor Leste border region possess moderate adaptive capacity. This suggests an elementary capacity for adjustment to environmental and socio-economic shifts, though it is not yet sufficiently robust to provide optimal support for business sustainability (Menghistu *et al*., 2021) .

The analysis of adaptive capacity (Y1) demonstrates that all sub-variables are in the moderate category, with varying levels of strength. The sub-variable of adaptability to the environment and climate (Y1.1) scored 64.4%, indicating that farmers have basic strategies in place, such as storing straw feed, using bran, or reducing herd size during the dry season. These measures are reactive and short-term in nature. Conversely, income from sources other than livestock farming (Y1.2) emerged as the most predominant at 74.4%, signifying that diversification into food crops, construction work, or small-scale trading has emerged as a prevalent strategy to mitigate reliance on volatile cattle farming, though it remains marginal in relation to comprehensive integration with livestock business planning (Garbole *et al*., 2025; Gondwe *et al*., 2025).

The sub-variable of access to information and innovation (Y1.3) attained a score of 71%, indicating that farmers acquire knowledge from extension workers, peers, or WhatsApp groups. Access remains inequitable, with remote villages frequently being overlooked in the dissemination of information regarding training or assistance programmes. The sub-variable of ability to build partnerships and implement adaptive strategies (Y1.4) also scored 71%, suggesting that while farmers have some experience partnering with groups, government, and traders, limitations with financial institutions and private actors persist due to administrative and trust barriers. The results of this study indicate that the level of partnership is still low. Partnership has also not had a long-term impact on increasing adaptive capacity. This result is consistent with the findings Ikhsan Rias and Yuzaria (2022) which explain that the level of partnership at the smallholder beef cattle farm level is still relatively low.

Table 4: *Adaptive capacity levels of beef cattle farmers*

Variable	Categories	Frequency (people)	Percentage (%)
Y1.1	Very low	15	3
	Low	124	24.8
	Moderate	322	64.4
	High	39	7.8
Y1.2	Very low	26	5.2
	Low	92	18.4
	Moderate	372	74.4
	High	10	2
Y1.3	Very low	27	5.4
	Low	98	19.6
	Moderate	355	71
	High	20	4
Y1.4	Very low	13	2.6
	Low	100	20
	Moderate	355	71
	High	32	6.4
Y1.5	Very low	14	2.8
	Low	118	23.6
	Moderate	349	69.8
	High	19	3.8
	Total	500	100

The sub-variable of ability to maintain business operations (Y1.5) scored 69.8%. It means farmers kept on practicing livestock farming even though there were feed shortages, price fluctuations, and diseases associated with the same type of business. Cultural values and social identities motivate and encourage them to persevere. Y1.5 scored 69.8%. It means farmers kept on practicing livestock farming even though there were feed shortages, price fluctuations, and diseases associated with the same type of business. Cultural values and social identities motivate and encourage them to persevere. This is supported by the findings of Alary and Gautier (2023), which indicated that dryness in areas where livestock farming systems prevail has to be accompanied by proper management of livestock and marketing strategies so as to anticipate prices during dry periods.

Assessment indicates that the adaptive capacity

variable (Y1) has moderate capacity but is not yet fully developed due to income diversification and sociocultural resilience. It is because of weak institutional support, limited access to technology, and fragile partnerships that contribute to the development of moderate capacity. Government policy strategies also need systematic interventions in human resource skills improvement, information systems that are inclusive, and building sustainable institutional partnerships. This policy strategy is meant to strengthen adaptive capacity and thus ensure sustainability when speaking about beef cattle farming in dryland border areas. The article written by Hilmiati *et al.*, (2024), can be said to reinforce the findings in this paper because theirs also found out that socio-economic and cultural approaches constitute important strategies for ensuring the sustainability of beef cattle farming.

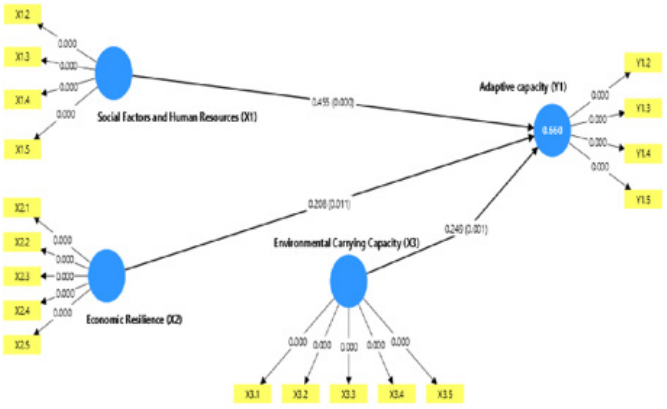

Figure 1: *Factors affecting the adaptive capacity of beef cattle farmers*

The Influence of social factors and human resources (X1), economic resilience (X2), and environmental carrying capacity (X3) on adaptive capacity (Y1)

This study used Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 4 for data analysis. The process started by looking at the outer model to check validity and reliability using measures like factor loading, Average Variance Extracted (AVE), Composite Reliability (CR), and Cronbach's Alpha. Any indicators that showed a loading below 0.50 were dropped from the model-those showing loadings of 0.50 or above were retained for further calculation with the help of bootstrapping (Hair *et al.*, 2021). The subsequent stage of the study project was to estimate the internal model by looking at R^2, f^2, and Q^2 as well as checking the significance of path coefficients between Social Factors and Human Resources (X1), Economic Resilience (X2), Environmental Carrying Capacity (X3) towards Adaptive Capacity (Y1).

Results obtained from running the PLS-SEM algorithm in SmartPLS 4 reveal that several sub-indicators of the Social and Human Resource Factors (X1) and Adaptive Capacity (Y1) variables have factor loading values below 0.50. This means that these sub-indicators do not have adequate strength to be retained as valid representatives of the latent constructs being measured and therefore do not meet the standard for convergent validity.

From the results of quantitative analysis using PLS-SEM, it can be seen that Social Factors and Human Resources (X1), Economic Resilience (X2), and Environmental Carrying Capacity (X3) positively and significantly affect the Adaptive Capacity (Y1) of beef cattle farmers in the dry climatic border area of Indonesia –Timor Leste with p-values < 0.05 for all paths. The R^2 value is 0.660 which means that these three independent variables together explain 66% variation in the farmers' adaptive capacity, and this is considered high based on (Hair *et al.*, 2021). The quantitative results observed are empirically aligned with the realities on the ground, illustrating a strong correlation among social, economic, and environmental factors that influence the survival strategies adopted by farmers within the researched region.

This study is consistent with realistic practicality in that, on matters of social dynamics and human resources (X1), farmers' adaptive capacity is mainly hinged on an experience in livestock management gained through a competence acquired from several generations. Social capital formed by participation in livestock associations, community meetings, and family networks provides very important avenues for the provision of information sharing as well as labor support and offers collective strategy formulation against environmental and market challenges. This was also established by Chepng'etich *et al.* (2024) whereby collaboration was found to be critical in enhancing the adaptive capacity of smallholder farmers. Where formal education levels are low and access to modern information limited, communal knowledge within the community has solidarity that has proved to be an effective alternative channel in enhancing social resilience. This finding agrees with what Ngongo *et al.*, (2022) said stressing the fact

that the credibility of these results is heightened by appreciating that usual manners- like the keeping of stock feed, land management out of experience, and the growing of socio-cultural cohesion- are key in improving adaptive capacity in border regions marked with scarcity of resources and ecological difficulties particularly in arid environments.

Bovine wealth does not only count as economic resilience (X2) but also as productive assets, household savings, and a measure of social standing. Changes in beef prices and the availability of other financial recourses have observed inspiring the farmers to take on diversification in their businesses. This can be in arid land food crop cultivation, agricultural by-product utilization, or any other small enterprise that will regenerate the family economy. This proves the findings Baffour *et al.* (2023) that indeed these strategies reduce economic vulnerability as well as capacity building for farmers to predict outside threats such as long dry spells and reduced consumer purchasing power.

The environmental carrying capacity (X3) has been the more relevant indicator due to environmental conditions in the area of Indonesia–Timor Leste border, characterized by low rainfall, long dry season, and poor feed resources. Farmers try to enhance the potential of their particular local environment by conserving post-harvest straw, alternative feed sources from local vegetation, and simple methods of livestock waste management which will reduce possible negative impacts on the environment. This agrees with the finding of Menghistu *et al.* (2021) that stated although there is limited access to modern feeding technology and a waste management system, ecological limitation as a principle of business sustainability can be achieved by adjusting enterprises with available resources at the local level.

The results of this study yield the fact that beef cattle farmers in dry, remote border areas are able to adjust because of an interaction between social capital strategies and economic strategies, and an effective plan to use local environmental carrying capacity. These three elements interact with one another as contextual mechanisms of adaptation to the geographical, social, and economic conditions prevalent in border communities. This is also supported by Zhang *et al.* (2023) saying adaptive capacity is shaped by social as well as economic capital. To enhance such adaptive capacities toward sustainability in such areas of beef cattle farming, thus human resource development access to capital and markets as well as new practice innovation in natural resources management compatible with ecological situations should be integrated.

Conclusions

Social capital, economic strategies, and the proper utilization of environmental carrying capacity form the basis of adaptive capability among beef cattle producers in the dry-land climate border region. Thus, there is a need to design an integrated policy that will work toward human resource development access to more financial resources and markets plus local resource management innovation for better sustainability of beef cattle farming at the border area between Indonesia and Timor Leste.

Recommendations

To raise human resource capacity through training programs and unify livestock associations, as well as open wider access to capital and business diversification, use local resource-based feed innovation and integrated waste management, and cross-sector integrated policy support are components that would fall under efforts in improving the adaptive capabilities of beef cattle producers in the dry climatic condition area on Indonesia's border with Timor Leste. Further study concerning the function of customary institution mechanisms, cross-border market dynamics, and long-term policies aimed at creating resilience for smallholder livestock farming is also required.

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Novelty Statement

The present study is innovative in its integration of social and human resource factors, economic resilience, and environmental carrying capacity,

thereby enabling a simultaneous examination of these factors' influence on the adaptive capacity of beef cattle farmers in the dry border region of Indonesia–Timor Leste. In contrast to previous studies that have focused on individual aspects, this study combines PLS-SEM analysis with contextual qualitative data, thereby providing a comprehensive perspective. The R^2 value of 0.660 confirms the strong role of social, economic, and environmental interactions, while the unique context of the arid border region offers new insights for the strengthening of locally based adaptation strategies.

Authors' Contribution

Ture Simamora: Conceptualization, editing, original draft
Stefanus Sio: Formal analysis, data curation, resources
Oktovianus Tabenu: writing - review
Bayu Eka Wicaksana: writing - review

Generative AI or AI assisted technology statement
No generative AI and AI-assisted technologies wer used in the writing process.

Conflict of interest
The authors have declared that there is no conflict of interest.

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