Global J. Environ. Sci. Manage. 10(SI): 279-302, 2024

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

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CASE STUDY

Sustainability index for eco-friendly cattle farming in dry climate regions

T. Simamora[1,2,*], M.N. Rofiq[2], L. Hutahaean[2], S. Sio[1], R. Hutapea[2], D. Irawan[2], Suryani[2], R. Diastuti[2], U.N. Thiyas[2], B.A. Correia[3], L.T. Correia[3]

[1] *Animal Husbandry Study Program, Faculty of Agriculture, Science and Health, Timor University, Indonesia*

[2] *Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia*

[3] *Department of Agricultural, Faculty of Agriculture, Timor Lorosa'e National University, Dili, Democratic Republic of Timor-Leste*

ARTICLE INFO

Article History:
Received 07 May 2024
Revised 11 July 2024
Accepted 16 September 2024

Keywords:
Dry climate
Eco-friendly
Multidimensional scaling (MDS)
Sustainability assessment

ABSTRACT

BACKGROUND AND OBJECTIVES: Cattle farming is an important pillar of dry climate agriculture. Cattle farming has even become the main engine of the community's economy. Currently, there are significant obstacles in the implementation of ecological, economic, technological, and infrastructural dimensions, alongside legal and institutional frameworks, that are essential for promoting sustainable livestock farming practices. Specific studies on different dimensional attributes affecting the sustainability of beef cattle are required. The objective of this study is to investigate different factors within four dimensions that affect the sustainability of cattle farming practices in dry climatic conditions.
METHODS: This study was conducted using an interview approach to respondents using a questionnaire or list of questions. The questionnaire contains questions on 37 dimensional attributes, including ten environmental, ten economic, ten technological and infrastructure attributes, and seven legal and institutional attributes. A range of responses was collected from individuals engaged in livestock management in the dry climatic conditions of Timor Tengah Utara Regency. The data that has been collected is analyzed employing Multidimensional Scaling and expedited appraisal software. To evaluate sustainability and leverage attributes, Monte Carlo analysis and the alternating least squares algorithm are applied.
FINDINGS: The study's outcomes revealed that the sustainability index pertaining to beef cattle farming in dry climates recorded an average score of 53.09 percent. This finding is based on the economic dimension of 45.58 percent, the environmental dimension of 54.18 percent, the technology and infrastructure dimension of 35.15 percent, and the legal and institutional dimension of 77.46 percent. The sustainability index, reflecting the technology and infrastructure aspects, ranks the lowest, primarily because the technological advancements necessary for achieving sustainable livestock farming are still underdeveloped. The availability of livestock waste processing technology is still relatively low and has not been processed optimally. This situation has an impact on the environment.
CONCLUSION: The sustainability index of dry climate beef cattle farming is greatly influenced by the attributes of technology and infrastructure dimensions. The enhancement of sustainability in the future necessitates careful consideration of specific factors, including the accessibility of waste and product processing technologies, advancements in information technology, and the development of road infrastructure. Attributes in the legal and institutional dimensions are the main factors supporting beef cattle's sustainability. Optimizing extension services by increasing the number of livestock extension workers is crucial in accelerating the dissemination of eco-friendly livestock technology and innovation.

DOI: 10.22034/gjesm.2024.10.SI.18

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NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
91	6	2

*Corresponding Author:
Email: *turesimamora@unimor.ac.id*
Phone: +62821 1455 5129
ORCID: 0000-0001-8331-5590

Note: Discussion period for this manuscript open until November 1, 2024 on GJESM website at the "Show Article".

INTRODUCTION

Dry climate livestock farms are farms run by small farmers in areas where the dry season is 7-8 months of the year (Burrow, 2019). In regions characterized by dry climates, the low levels of rainfall lead to a constrained supply of water. This limitation on water resources poses a critical challenge that influences every aspect of livestock business activities (Halimani *et al.,* 2021). Dry climate farms in Indonesia are generally managed extensively and semi-intensively to optimize meat production (Balaji *et al.,* 2023). In the context of dry climate agriculture, beef cattle serve as the foremost commodity. These farms are mainly located in the eastern part of Indonesia, with Nusa Tenggara Timur (NTT) Province being particularly noted as a central region for the cultivation of beef cattle in arid environments (Kana Hau *et al.,* 2021). The beef cattle commodity commonly reared is a breed of Balinese cattle known as Timor Cattle (TC). This local livestock is different from other cattle in Indonesia. This is due to its high adaptive ability in dry climate (Habaora *et al.,* 2019). In the NTT region, rainfall occurs for roughly five months each year. The pronounced effects of the dry climate on beef cattle farming have impacted various environmental and economic factors. Traditional livestock management also requires the development of technology and infrastructure and optimizing institutional roles in supporting sustainability. The focus of research on livestock sustainability indices has primarily been on fertile land. In opposition, dry land presents distinct characteristics, including variations in climate, soil types, and constraints related to water availability. Analysis of adaptive livestock production systems, including using livestock species more resistant to dry conditions, water harvesting technology, and alternative feed management, must be studied based on sustainability indices. The analysis of socio-economic and institutional factors in dry climate livestock farming is currently limited. The sustainability of these farming systems is fundamentally linked to the local capacity for adopting sustainable agricultural practices. Other waste management problems and energy use in dry climate livestock farming are often overlooked. Research to analyze the multidimensional dry climate livestock sustainability index that combines environmental, social, economic, and institutional aspects to provide a more comprehensive picture. Despite the dry and hot climate, the region has potential for beef cattle development (Ahmad *et al.,* 2022). This makes the area a dryland farming area (Burrow, 2022). One of the aspects affected by this water limitation is feed production, which decreases during the dry season (McLeod *et al.,* 2020). The availability of forage feed throughout the year is a factor that needs to be considered by farmers. Alternatively, there exists considerable development potential within dryland farming. This potential is reinforced by favorable natural resources, including substantial land available for grazing and the opportunity to cultivate locally accessible fodder crops (Rahimi *et al.,* 2022). Dryland farming has developed into one of Indonesia's important beef cattle farming centers, contributing significantly to beef production in Indonesia. Presently, dryland farming encounters several significant challenges, such as the reduced availability of feed during the dry season, which negatively influences the growth of beef cattle. Furthermore, the productivity of livestock is hindered by inbreeding, and there is a lack of technological advancement and innovation in the livestock sector (Tiro *et al.,* 2023). The concept of sustainable development of dryland farming is needed. This includes good feed management, health care, environmental management, and selection of quality breeds to ensure optimal growth and health. Given the vital importance of beef cattle farming in fulfilling the growing demand for beef alongside the increase in human population, the implementation of a sustainable farming system is crucial (Widyas *et al.,* 2022). Sustainable beef cattle farming development is an approach that considers the economic, social, and environmental aspects of its operation (El Ansari *et al.,* 2020). This approach can be done by measuring sustainability using the multidimensional scalling (MDS) method (Mashur *et al.,* 2022). his strategy presents an alternative avenue for generating insights that can aid in the creation of sustainability frameworks for beef cattle in areas characterized by limited moisture. To realize the sustainability of beef cattle farming in drylands requires identifying and analyzing dimensions based on ecology, economy, technology, infrastructure, law, and institutions. The four dimensions need to identify attributes that become factors that determine the sustainability index (Rohaeni *et al.,* 2024). The essential features of sustainable beef cattle development involve the

stewardship of natural resources, strategies for disease prevention and management in livestock, the responsible handling of livestock waste, energy management practices, the use of sustainable technologies, the fortification of farmer cooperative communities, and the facilitation of innovation adoption (Perdinan *et al.,* 2024). Applying a holistic and sustainable approach to beef cattle development is expected to increase livestock production while maintaining environmental sustainability. Research by Kapa *et al.* (2019) showed that technology is needed to sustain local cattle development in drylands. The most important attribute is the extensive rearing system based on the technology dimension. The study demonstrated that in order to promote the sustainability of the beef cattle business, it is crucial to consider six specific attributes. Indrayani *et al.* (2024) stated that the sustainability index of livestock farming in coastal areas is economically, ecologically, and technologically entirely sustainable. The institutional dimension needs to optimize its supporting attributes. Zaied *et al.* (2021) explained that the impact of drought greatly affects the sustainability index of beef cattle, especially the attribute of fluctuations in the selling price of beef cattle in the economic dimension. Mashur *et al. (*2022) identified 90 sustainability attributes with six beef cattle feed bank development dimensions. Based on this identification, in general, the sustainability status of feed banks is less sustainable. Riera *et al.* (2023) suggested that increasing the sustainability index of beef cattle farming needs to be done by collaborating the economic and environmental dimensions. Enhancing the sustainability index of livestock farming can be achieved through the integration of agricultural operations. Attributes in the social and economic dimensions are attributes that determine the status of sustainability (Widjaja *et al.,* 2024). Susanty *et al.* (2021) explained that achieving optimal sustainability in beef cattle development requires targeted efforts to improve critical attributes. This is necessary because attributes affect the sustainability index of each dimension (Allaily *et al.,* 2024). In light of the preceding description, it is imperative to conduct a study on the sustainability of beef cattle farming. This research will provide valuable insights for the government and other involved parties to develop strategies that ensure the sustainable advancement of beef cattle farming in the years to come. Analyzing the sustainability of beef cattle farming in drylands is a study that is needed now. The present study suggests that offering detailed insights into sustainability could facilitate the advancement of small-scale beef cattle farming within the dry climatic conditions of Indonesia. The objectives of this study are: 1) to identify the sustainability of beef cattle in dry climate based on dimensional attributes; 2) to measure the sustainability status of beef cattle farming in dry climate based on the dimensions of ecology, economy, technology, and infrastructure, and law and institutions. This study has been carried out in Timor Tengah Utara (TTU) Regency in 2023

MATERIALS AND METHODS

Site location and *data collection*

This study was carried out in TTU Regency, NTT province, from July to December 2023, as depicted in Fig. 1. The total area of TTU Regency is estimated to be around 2,669.70 square kilometers (km²). This region is classified under the tropical climate category, featuring two significant seasons: the dry season and the rainy season. The dry season usually lasts from April to October, while the rainy season lasts from November to March. Temperatures in this region range between 20 and 30 degrees Celsius (°C), with rainfall varying in different parts of the region but generally between 1,000 and 2,000 millimeter per year (mm/y). Focus group discussions (FGDs) were held with entrepreneurs from several cassava manufacturers in six districts of NTT. A series of questionnaires were issued to specialists in dryland agriculture management, extension workers, heads of livestock administration, experts in beef cattle, and individuals engaged in business activities. FGDs were used to facilitate data collecting at each factoryThe focus group discussions were conducted to investigate the current involvement of business actors in supporting dryland agricultural resources in the study area, with the intention of generating information that would facilitate the identification of sustainability dimensions and characteristics.

Characteristics of the Indonesian dry climate

Dry climate livestock farming has characteristics that are influenced by geographical conditions, climatic conditions, and socio-economic conditions of the community. The climatic conditions of drylands

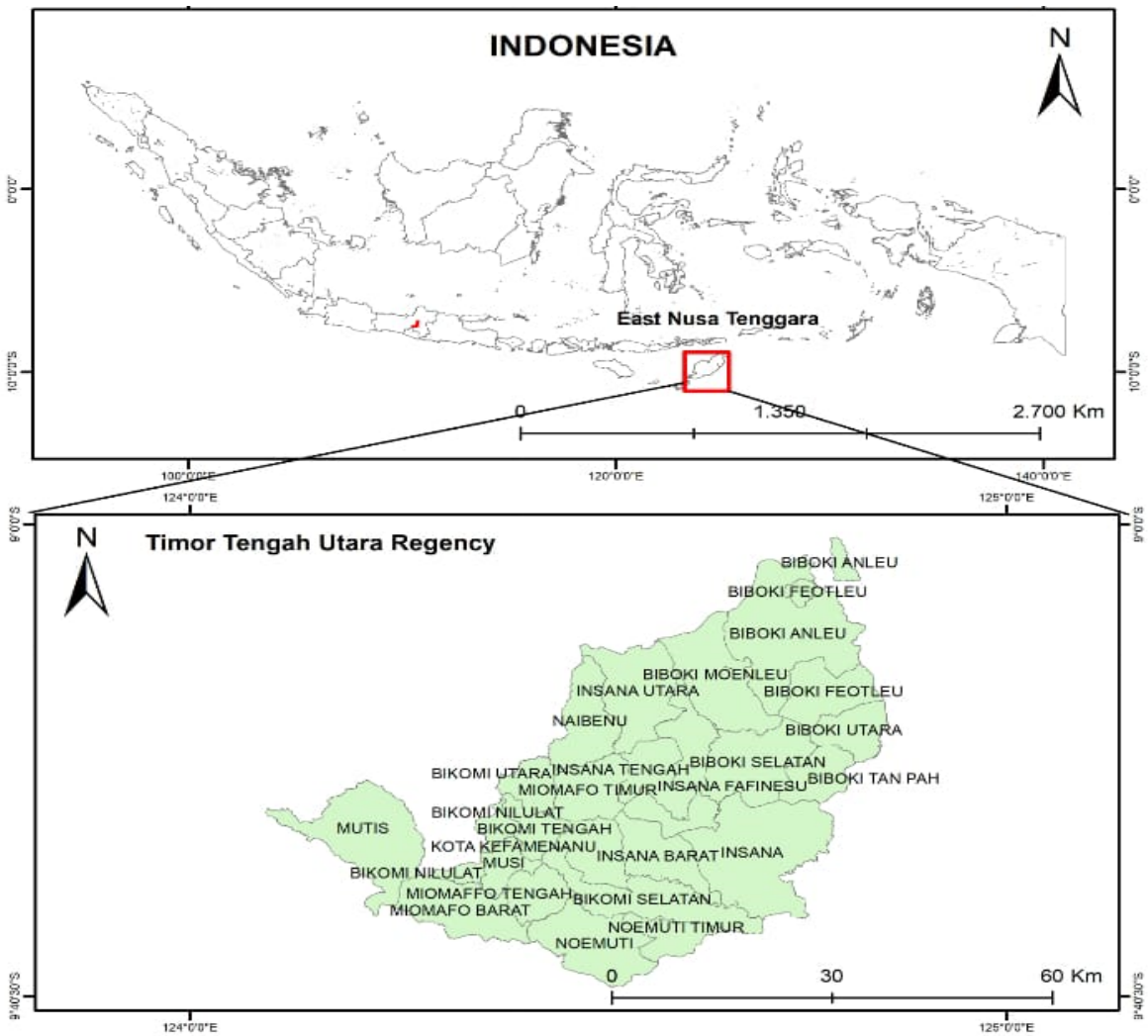


Fig. 1: Geographic location of the study area in dryl climate farming Timor Tengah Utara Regency, Nusa Tenggara Timur Province, Indonesia

have established semiarid practices as a defining feature of animal husbandry, a tradition that persists to the present day. Annual rainfall ranges from 800-1500 mm, with uneven distribution of rain affecting food availability throughout the year. In regions characterized by dry climates, it is common to find Bali cattle breeds that have adapted effectively to these conditions. The prevailing systems of livestock rearing in these farms are largely extensive and semi-intensive.

Data collection

The method of obtaining secondary data involves collecting data from dryland agroforestry guidelines, research journals, and other literature related to income and the sustainability of dryland management. Original information was obtained through observational methods, alongside direct interviews that utilized questionnaires. The respondents were deliberately selected for their active participation, competence, and extensive knowledge regarding dryland agriculture in NTT. Several respondents were determined based on the specified respondents' criteria, including individuals from the village government, the Agriculture Agency, members of farming groups, and various experts associated with dryland agriculture management.

Data analysis

The sustainability analysis of community forest management was conducted using the MDS approach employing the rapid appraisal for private-forestry analysis tool (Rap-Pforest). The identified attributes demonstrate the extent of sustainability across various disciplines, tailored in accordance with the availability of information pertaining to the characteristics of the resources being studied (Pitcher and Preiskhot, 2001). The MDS approach was used to analyze the sustainability of dry climate farming management using the Rapid Appraisal for Dryclimate Analysis tool (Rap-dryclimate). This MDS method has been selected due to its capacity to deliver clear, swift, and objective results regarding the factors that impact duration, which simplifies its implementation in legal environments. There are several steps involved in using MDS, including determining attributes and values through conversation, calculating, and assigning a score in an ordinal range from 0 (fake) to 2 (good) based on the attributes that the respondents carefully considered or based on the available data (primer and secondary). The next step is to do an MDS ordering concerning the leverage factor (leverage factor) analysis of the attributes based on Root Mean Square (RMS) in axis X. The final phase involves conducting a Monte Carlo analysis to assess the influence of scoring errors. The evaluation of measuring instruments is derived from the outcomes of distributing these instruments to various relevant stakeholders beyond the designated respondents. This testing is carried out by distributing questionnaire data on the level of attribute importance, which is then processed using validity and reliability tests. Validity tests are used to determine whether the questions that have been designed are valid or not. Reliability assessments evaluate the extent to which a measuring instrument produces stable and consistent value outcomes. The selected attributes reflect the level of sustainability in each discipline, adjusted based on the availability of information about the characteristics of the studied resources (Pitcher and Preiskhot, 2001). There are four dimensions: environment, economics, technology and infrastructure, and institutional law. This study used 37 attributes (Table 1). A Likert scale-based questionnaire is then utilized to describe the dimensions and qualities. Expert reviewers evaluated the items in the questionnaire, providing scores of 0, 1, or 2 to indicate whether the responses were inadequate, average, or reasonable.

Analysis of the sustainability of dry climate livestock farming

The levels of sustainability performance are divided into four levels, resulting in intervals of 0 percent (%), 25%, 50%, 75%, and 100%. The assessment categories are listed below: 0,00 - 25, poor category, unsustainable; 25,01 - 50, less category, less sustainable; 50,01 - 75, adequate category, relatively sustainable; 75,01 - 100, excellent category: sustainable (Arofi *et al.,* 2015). Leverage analysis serves as a tool for identifying characteristics that are particularly responsive to sustainability considerations. The indicators with the highest root mean square (RMS) values are deemed the most sensitive (Pitcher and Preikshot, 2001). The leverage factors exhibit values ranging from 2% to 8%, suggesting a moderate to favorable influence. If < 2%, the factor is considered not influential, while if > 8%, the factor is considered dominant (sustainable), according to (Pitcher and Preikshot, 2001). Table 2 illustrates the influential factors that play a significant role in the analysis.

The Monte Carlo approach helps calculate errors and estimate uncertainty in MDS. If the discrepancy between the MDS and Monte Carlo values is modest, the MDS analysis for establishing sustainability is 95% accurate.

RESULTS AND DISCUSSION

The progression of beef cattle farming in dry climates, facilitated by the integration of innovation and technology, has the potential to achieve sustainable agricultural outcomes. This strategy is consistent with the global sustainable development goals, focusing on enhancing productivity while adhering to eco-friendly principles. The development of sustainable livestock farming in dry climate is essential, taking into account four main dimensions: environment, economy, technology and infrastructure, as well as law and institutions. According to Stanley *et al. (*2023), there is a great deal of variation in the sustainability results of cattle systems. The variables encompass the types of goods manufactured, the nature and extent of land utilized, as well as the amounts and types of inputs employed. Although the environmental sustainability of animal production has been well studied, there

Table 1: Dimensions and attributes of dry climate farms

Dimensions	Attributes
Environment	1. The beef cattle pen's hygiene 2. Accessibility of agro industrial wastewater treatment facilities for goods derived from beef cattle 3. Accessibility of feed for beef cattle 4. Shifting cultivation activities 5. The ability of natural pastures to carry 6. Land (fertility of the soil) 7. Effective use of resources and energy in systems for raising beef cattle 8. System of raising beef cattle 9. Using agricultural waste to produce animal feed 10. Beef cattle manure is used to make organic fertilizer
Economy	1. Industry availability feed 2. Innovation in product marketing 3. Farmer's place sell his livestock 4. Market demand for beef cattle products 5. Agro-industrial product market farm 6. Transfer of profits from beef cattle farming business 7. Average income of breeders against regency minimum wage 8. Contribution to Original Regional Income for the agricultural sector 9. Contribution to gross domestic product 10. Advantages in cultivating beef cattle farming
Technology and infrastructure	1.Mastery level beef cattle cultivation technology 2. Availability of infrastructure/public facilities and infrastructure 3. Availability of agribusiness facilities and infrastructure 4. Information Technology and transportation 5. Technology for processing beef cattle products 6. Livestock agro-industry waste processing technology beef cattle 7. Feed technology 8. Use of vitamins and probiotics for livestock 9. Post distribution artificial insemination (AI) services 10. Place distribution Animal health post
Legal and institutional	1. Cooperation agreements with other regions about animal husbandry 2. Suitability central and regional policies 3. Livestock farmer groups 4. Availability of local wisdom rules for beef cattle farming 5. Agricultural/livestock extension institutions 6. Management body agropolitan area 7. Livestock Cooperative Beef cattle

Table 2: Parameter values of the leverage factor

No.	Factor value (%)	Category	Description
1	<2.0	Neutral	Not influential
2	2-8	Influential	Moderate to good impact
3	>8.0	Significant	Dominant

hasn't been much focus on the combined evaluation of environmental, economic, and social sustainability. To identify opportunities for improvement while avoiding without imposing additional burdens. further research based on this expansive understanding of sustainability is required. According to the analysis conducted using the rapid appraisal of beef cattle (Rap-SAPOT) approach, the ecological dimension shows 54.18% with a status of fairly sustainable, the economic dimension shows 45.58% with a status of less sustainable, the legal and institutional dimension shows 77.46% with a good status and the infrastructure and technology dimension shows 35.15% with a status of less sustainable. The results of the Rap-SAPOT analysis are illustrated in Fig. 2, which reveals the sustainability index values for four

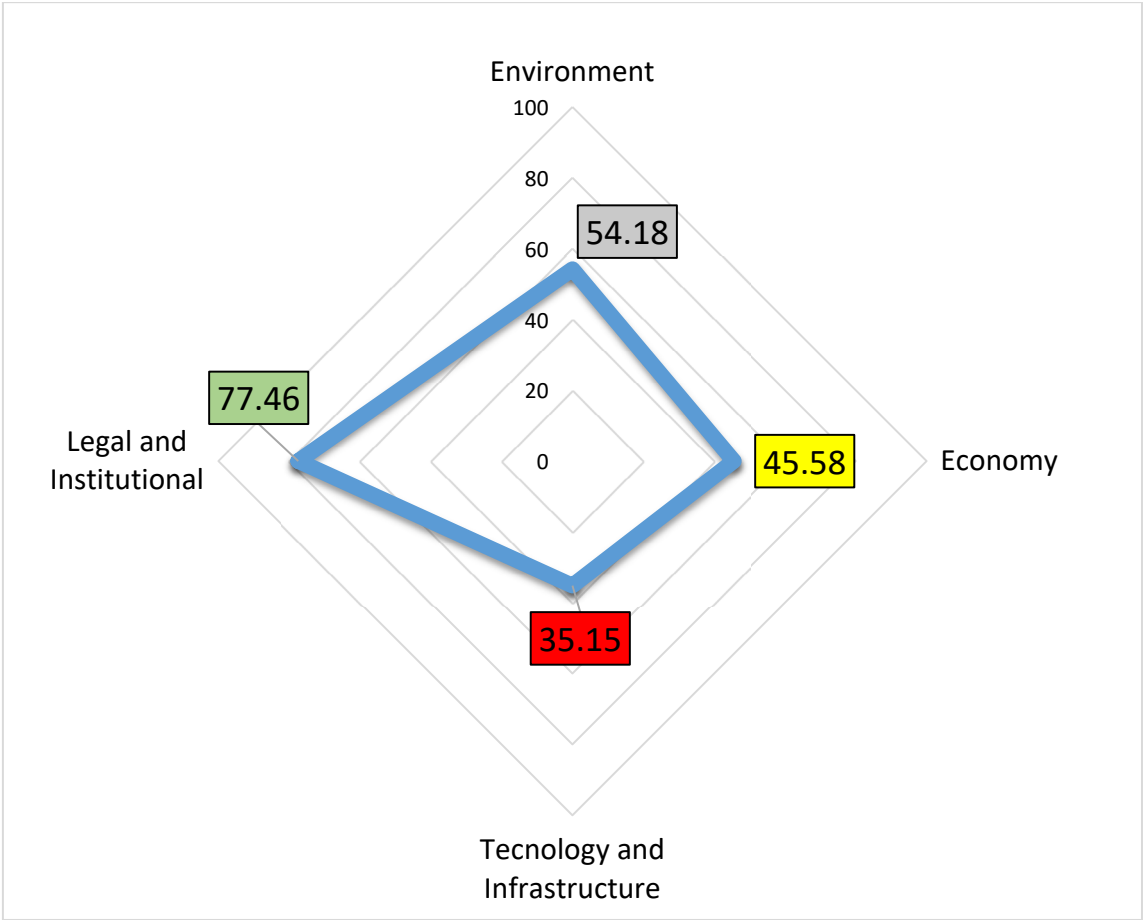


Fig. 2: Multidimensional sustainability of dryland beef cattle farming

dimensions that could be further developed in the future.

Environment dimension

MDS analysis shows that the index value of the ecological dimension is 54.18, the second highest after the legal and institution dimension. The influence of environmental factors on the beef cattle industry has led to modifications in livestock selection aimed at producing resilient breeds capable of thriving in arid climates. This includes the adoption of improved grazing techniques, supplementary feeding strategies, and enhanced management practices (Márton *et al.*, 2023). The environment influences the sustainability of the beef cattle farming business and farmer income in dry climate areas (Rohaeni *et al.*, 2024). The environmental dimension plays an important role in managing beef cattle businesses. Environmental impacts influence the management characteristics of eco-friendly livestock management (Vechi *et al.*, 2022). In Indonesia, especially in its eastern region, environmental issues have not yet emerged as a top priority. The sustainability of beef cattle farming in arid climates is notably affected by two key factors: the hygiene of the beef cattle pen, which has an RMS value of 8.10, and the availability of ago-industrial wastewater treatment facilities for products related to beef cattle, with an RMS value of 7.78. These findings are illustrated in the leverage analysis depicted in Fig. 3. The other attributes do not have a significant impact, but still need to be managed to maintain the ecological dimension in sustainability of beef cattle farming on dry climate. Hygiene within the beef cattle pen is the key element

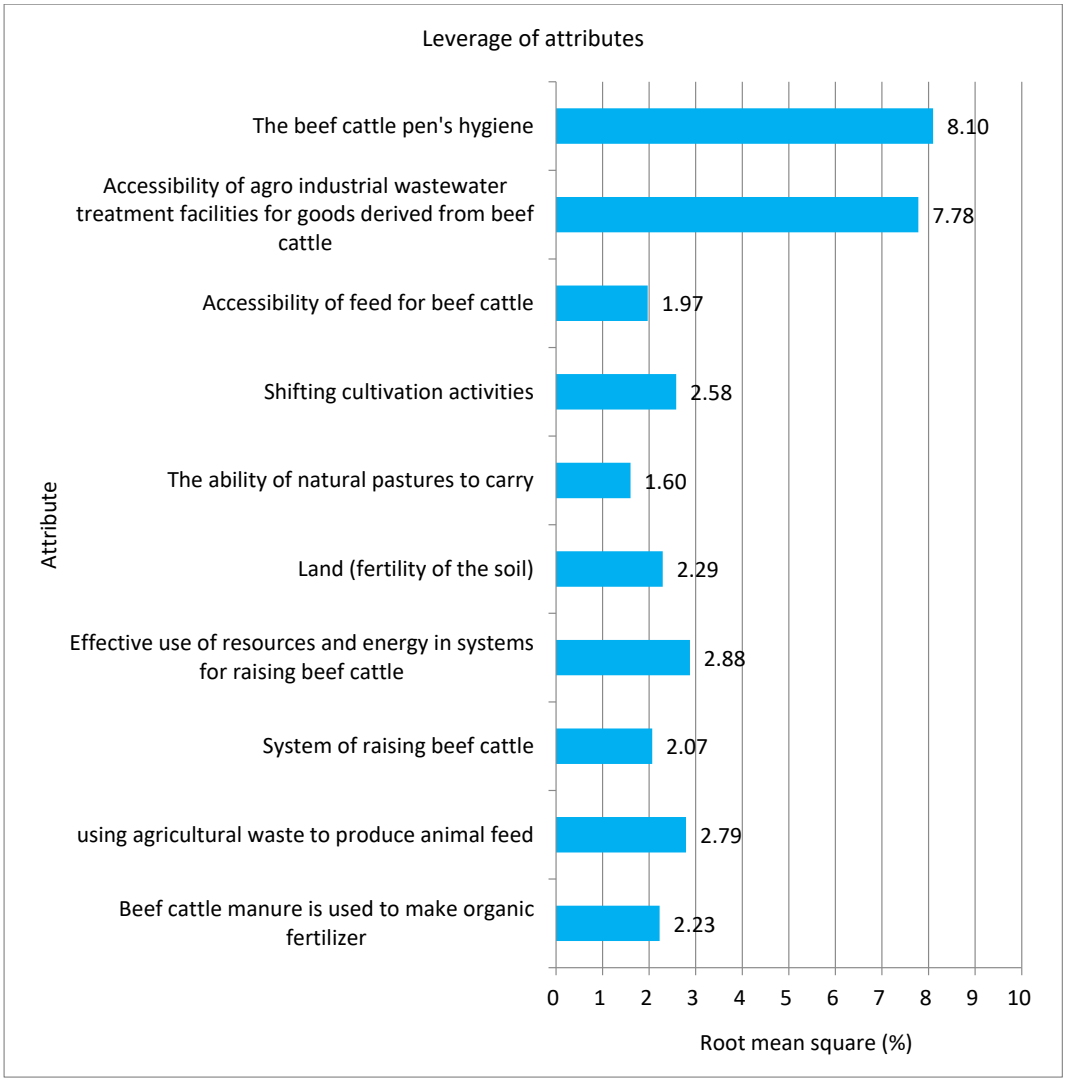


Fig. 3: Leverage attribute for environment dimension

that profoundly affects the sustainability of beef cattle farming in TTU Regency. Even though this area is a dry climate area with limited water sources, the cage's cleanliness must always be maintained. Beef cattle farms in dry climates face challenges in water requirements for barn cleanliness. Farmers are sometimes forced to buy water to clean the barn. To address the challenges of limited air circulation during the dry season, farmers ensure that the barn is cleaned every day. A well-maintained pen is crucial for the well-being of beef cattle, and the cleanliness of the barn environment plays a vital role in determining the quality of beef produced (Moustsen *et al.,* 2023). Cows that live in clean pens tend to have better health and a lower risk of contamination, which can affect the meat quality (Brown *et al.,* 2023). Clean and orderly pens help increase beef cattle production efficiency (Pampori *et al.,* 2023). Animals that inhabit a clean environment are likely to experience superior growth, more effective feed utilization, and elevated reproductive rates. The establishment of wastewater treatment industries for livestock in the TTU Regency is vital for promoting sustainability (Grell *et al.,* 2023).

Several reasons why this is important include;

waste from livestock, including liquid waste, can pollute groundwater and rivers if not appropriately treated (Vaishnav *et al.,* 2023). The wastewater treatment plays a crucial role in purifying waste prior to its discharge into the environment, thereby mitigating its adverse effects on ecosystems and public health (Ibekwe *et al.,* 2023). Livestock waste that is not processed correctly can be a source of disease for animals and humans (Richards *et al.,* 2023). Proper waste disposal is essential for lowering the likelihood of disease transmission, which in turn supports the well-being of farms and their surrounding areas (Koyun *et al.,* 2023). Waste from livestock can be processed into alternative energy sources or organic fertilizers (Odejobi *et al.,* 2023). The wastewater treatment industry can help optimize the utilization of such waste, increase resource efficiency, and promote circular economy principles (Smol, 2023). Considering these various elements, the establishment of wastewater treatment industries for livestock is vital for maintaining the long-term viability of the livestock industry. This attribute is closely related to the supporting attribute of the availability of beef cattle waste processing technology in the technology and infrastructure dimensions. Both attributes are essential parameters in the sustainability of dry-climate beef cattle. The role of these two attributes plays a crucial part in enhancing the income of livestock farmers by facilitating the sale of organic fertilizer produced from livestock waste. The availability of this livestock wastewater processing industry is intended to accommodate and process liquid waste produced by livestock farms in the TTU Regency. This waste includes animals, urine, and other waste that can pollute the environment if not managed properly. The process entails the filtering, isolating, and diminishing of hazardous substances found in waste, which contributes to a reduction in their adverse environmental impact (Sathya *et al.,* 2023). The availability of livestock wastewater treatment industry also serves to help prevent environmental pollution (Qi *et al.,* 2023), including pollution of groundwater and rivers around livestock. It is essential to maintain a balance within local ecosystems to support the health of communities that depend on these natural resources. Furthermore, the incorporation of agricultural waste as animal feed is a key component in promoting the sustainability of beef cattle farming. As has been reported, agricultural waste contains quality nutrients to meet the nutritional needs of livestock (Alan *et al.,* 2023). Using agricultural waste can reduce organic waste and is more economical for farmers. The availability of land for green fodder and the selection of superior livestock are essential factors in maintaining the sustainability of beef cattle farming (Tulu *et al.,* 2023; Ayalew *et al.,* 2023). Having enough land to grow forage, including grass, legumes, and hay, is crucial for satisfying the dietary needs of beef cattle. This forage acts as the primary nutritional resource for the cattle, impacting both their health and productivity levels (Henn *et al.,* 2024). The combination of land availability for green fodder and the selection of superior livestock is an essential strategy for maintaining the sustainability of beef cattle farming. This ensures that livestock can access sufficient and quality feed while optimizing production potential to meet market demand sustainably. Optimizing local feed plants such as lamtoro teramba, which is resistant to heat stress and can grow in dry climates, is an effort farmers make to meet feed availability, especially in the dry season. By implementing regular pruning, fresh lamtoro leaves can be sourced continuously throughout the year. Enhancing livestock productivity involves leveraging feed production, especially within pasturelands. The government still possesses adequate pasture areas that are advantageous for all livestock producers. The government has begun implementing a sustainability-based livestock policy by presenting a livestock integration program with agriculture. One of the government's programs in supporting the poverty of beef cattle farming is the expansion of hybrid corn planting that is resistant to dry climate conditions and supported by sprinkler technology. This policy aims to boost the output of feed concentrate from corn and optimize the use of corn residues for silage. Furthermore, the processing of livestock waste into organic fertilizer significantly enhances the sustainability of this integrated approach.

Economic dimension

Indicators of sustainability in the economic dimension require that the development of a business or product must be competitive and financially profitable economic sustainability is essential for the advancement of businesses that create a range of high-value-added products. This necessity also entails

fostering economic growth at a sufficient pace to enhance the well-being of individuals (Munasinghe, 2019). Some important aspects that must be considered in supporting the sustainability of beef cattle farming include production efficiency (Terry *et al.,* 2021), income diversification (Asante *et al.,* 2018), risk management (Meraner and Finger, 2019), capital and access to finance, increasing added value (Wegari and Gelata, 2021). By evaluating these elements, beef cattle farming can be advanced in a way that guarantees enduring economic sustainability, which serves the interests of farmers, society, and the environment alike. Based on the results of the Rap-beef cattle analysis, the economic dimension is included in the less sustainable criteria with a value of 45.58. The results of the leverage analysis show that there are four most sensitive attributes in the economic dimension, namely the availability of the feed industry (4.67), the availability of livestock marketing innovations (4.64), and the contribution to gross domestic product AI (4.43) and contribution to original income for the agricultural sector (3.68). The high leverage index indicates that these four traits are vital to the evolution of sustainable beef cattle farming practices (Fig. 4). As the global population continues to rise and the demand for food escalates, the feed industry will play a crucial role in ensuring the sustainability of beef cattle farming. This must be addressed in the context of climate change, evolving socioeconomic factors, the growing influence of

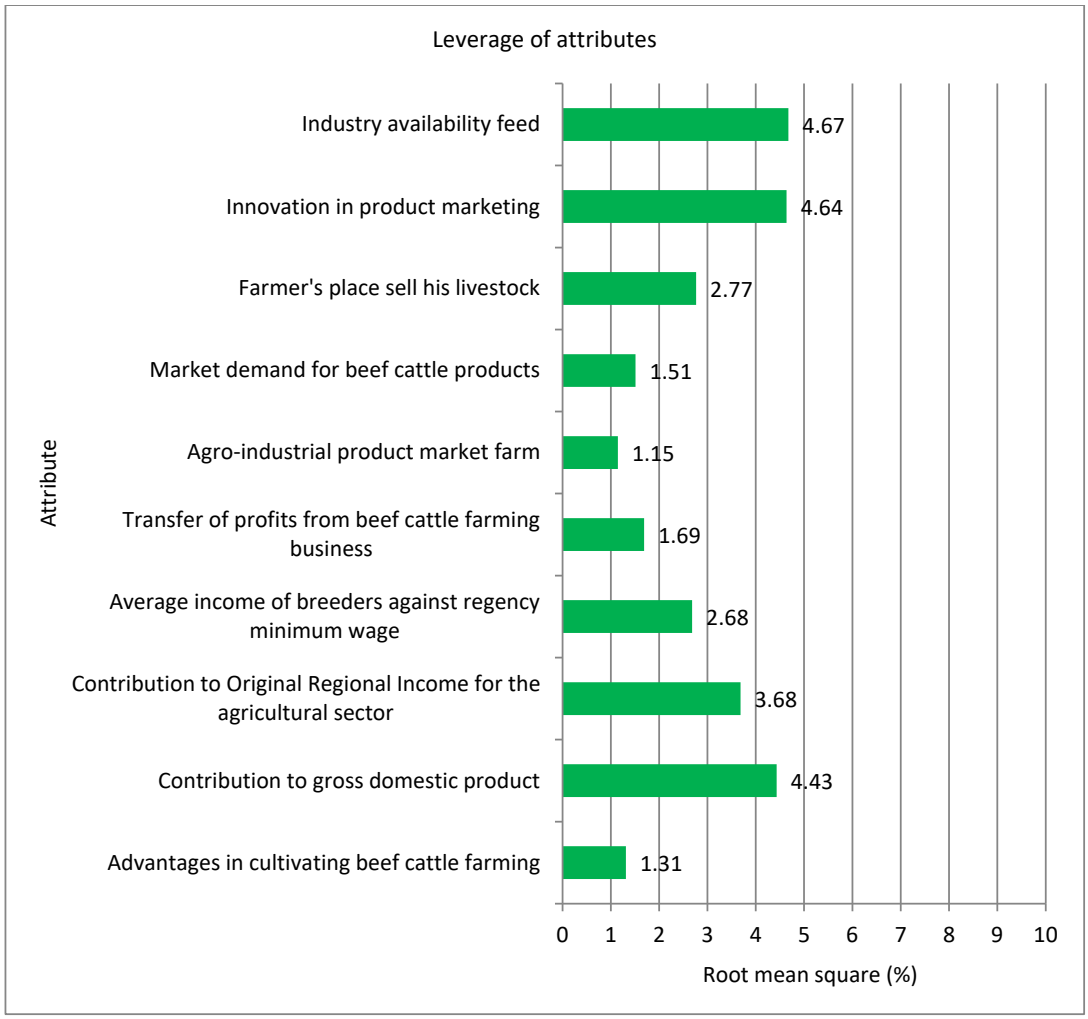


Fig. 4: Leverage attribute for economic dimension

media, and ongoing initiatives aimed at enhancing efficiency (Uddin and Kebreab, 2020; Coffey *et al.,* 2016; Clark *et al.,* 2020). The availability of animal feed affects the quality and productivity of beef cattle (Bunmee *et al.,* 2018). A balanced nutritional regimen for beef cattle leads to superior growth, greater meat output, and an overall improvement in their health condition (Pighin *et al.,* 2016). NTT Province is one of the centres of beef cattle farming, but the results of feed potential mapping show that the region is a feed deficit area, one of the efforts that need to be done is to develop a cheap complete feed industry with local raw materials (Ilham, 2015). The availability of the animal feed industry not only increases livestock productivity and farmers' income, but also reduces dependence on feed supplies from outside the region, thereby increasing local feed security. The significance of the animal feed industry lies in its ability to foster innovation and progress in the development of feed formulations that are both efficient and environmentally friendly, focusing on the incorporation of local raw materials and enhanced processing techniques. The attribute of the availability of the feed industry is closely related to the attribute of the availability of feed processing technology in the dimensions of technology and infrastructure. Farmers greatly need the feed industry's existence to continuously ensure feed availability, mainly concentrate feed, at a more competitive priceTo establish an eco-friendly feed industry, it is essential to adopt modern technologies that effectively address the requirements of a dry climate. The availability of a feed factory that can produce concentrate feed according to the formulation of beef cattle needs is greatly needed to provide for the needs of farmers. This condition will have an impact on the ease of access for farmers to buy cheaper livestock feed rations, which can reduce production costs. According to studies focused on duck business development, the viability of livestock operations is significantly affected by the presence of locally sourced feed (Hutahaean *et al.,* 2022; Bakrie *et al.,* 2023). By utilizing local resources, the animal feed industry can also reduce unemployment by creating jobs and contributing to economic growth. In addition, using local ingredients in the animal feed industry can maintain the sustainability of natural resourcesAccording to the research conducted by Chia *et al.* (2019), insects offer promising potential as affordable, high-quality, and sustainable components for animal feed. The inclusive business model of animal feed from insect raw materials can contribute to solving the environmental, economic, and social problems of developing countries. Ilham (2015) stated that using biomass or waste from plantations as a source of animal feed is an alternative to solving the limitations of green fodder. Significant by-products are produced by the oil palm, coffee, cocoa, coconut, and rubber plantation subsectors, and feed processing technology is employed to develop concentrated feed that maintains a balanced nutritional composition (Aswanto *et al.,* 2023). Marketing innovation in product development has a positive role in increasing profits and product-added value. The availability of marketing innovations is essential for business sustainability, namely by increasing accessibility to marketing institutions, product diversification, creating strong branding, unique product offerings, and market differentiation (Hermansyah *et al.,* 2023). Innovations in marketing will emerge through the integration of digitalization and technology, enhanced training and education, collaborative partnerships and networks, improved infrastructure and logistics, favorable government policies, and the availability of funding, and financing. In the context of beef cattle farming, the relationship between the availability of product innovation attributes and product processing technology attributes is significant to improve the efficiency, quality, and competitiveness of beef products. Enhanced beef processing methods empower livestock companies to deliver meat products of higher quality. For example, precision cutting, cooling, and packaging technology can improve meat quality, extend shelf life, and maintain product cleanliness. The existence of product processing technology is also related to the availability of product innovations that have a high health value, such as low-cholesterol meat. By employing the appropriate processing technology, it is possible to manufacture these innovative products in significant volumes without compromising on quality. Processing technology allows product diversification in the beef cattle industry, such as producing meat with various levels of tenderness, fat content, or unique cuts to meet different market tastes. By diversifying, livestock companies can generate additional value as they pursue innovation in different market sectors. Degila

et al. (2023) stated that the digital transformation of agriculture in African countries can improve food security and economic growth. Adequate infrastructure support for mobile internet usage is a key element in fostering the growth of digital agriculture. To be competitive and self-sufficient in the global e-economy, a country must accelerate change by implementing digital agriculture through effective governance and the synergy of policy programs in various sectors. Beef cattle farmers in North Central Timor District mainly market their products to one village trader who has become a farmer's regular, and some also because there is a loan relationship as a guarantee for the trader so that the farmer does not sell the cow to another livestock trader. Cattle pricing is influenced by evaluations of the cows' body condition, resulting in selling prices that are often disappointing for farmers, who struggle with limited negotiating power (Lole *et al.,* 2021). The limited accessibility of marketing institutions causes the selling price of livestock at the farm level to remain low compared to the selling price in the market (Gobena, 2017). To facilitate better access to marketing institutions, it is crucial to institutionalize beef cattle farmers. Livestock institutions play an essential role in the sustainability of household-scale livestock businesses.

To leverage marketing innovations, it is essential to expand the range of beef cattle products, incorporating processed meats and additional by-products. Diversification can increase farmers' income and add value to their products. Beef cattle farmers have tended to sell live cattle, and product innovation will increase added value. Processing fresh beef into se'i (smoked beef), shredded beef, and jerky products has the potential to boost the added value for farmers in Kefamenanu (Sikone *et al.,* 2022). The research results by Lole *et al.* (2021) stated that the marketing chain of livestock products, processed meat products, and cattle waste has yet to fully and solidly form in NTT. The sustainability of cattle production and marketing is significantly impacted by village traders, who have a direct effect on the earnings of farmers and those involved in slaughterhouse operations. At the same time, the processing of processed meat products and livestock waste needs to be better managed. Gross domestic product (GDP) is an indicator assessing a region's economic performance and welfare. Conversely, revenue generated locally from the agricultural sector evaluates the region's financial ability to support public programs and services. It encourages the region to increase the local economic potential of agricultural activities. This definition indicates that the contributions of GDP and local own-source revenue derived from the agricultural sector are pivotal variables in evaluating sustainability in the economic context. The agricultural sector in NTT is the largest in labor absorption. it contributes significantly to the gross regional domestic product (GRDP) but has yet to become the primary source of economic growth in the NTT economy (Koylal *et al.,* 2022). As reported by Statistics Indonesia in 2023, NTT Province has the third-highest poverty rate in Indonesia. This economic hardship poses a significant obstacle for beef cattle farmers, limiting their access to the resources necessary for successful business management. Limited resource access to land, quality animal feed, animal health services, and other supporting infrastructure. This limited access hinders the growth and productivity of beef cattle farming, which is a significant source of economic activity in NTT.

Technology and *infrastructure dimensions*

Technology and infrastructure are essential aspects that can influence the sustainability of beef cattle businesses in dry climate regions. The adoption of suitable technologies and the establishment of robust infrastructure can enhance the welfare of beef cattle, boost productivity, ensure adherence to environmental regulations, and support the sustainable growth of livestock enterprises. The technology and infrastructure dimensions have low values because the level of existence and availability of attributes, especially technology and information facilities, is minimal. Areas engaged in livestock farming, predominantly situated in the isolated regions of the Indonesia-Timor Leste border, have not been provided with sufficient road infrastructure. The results of the analysis of the sustainability index from the technology and infrastructure dimensions of beef cattle businesses in the dryland of NTT show that at least 4 (four) essential attributes influence the business's sustainability (Fig. 5). Essential attributes encompass expertise in technology, availability of agribusiness facilities and infrastructure, availability of public facilities and infrastructure,

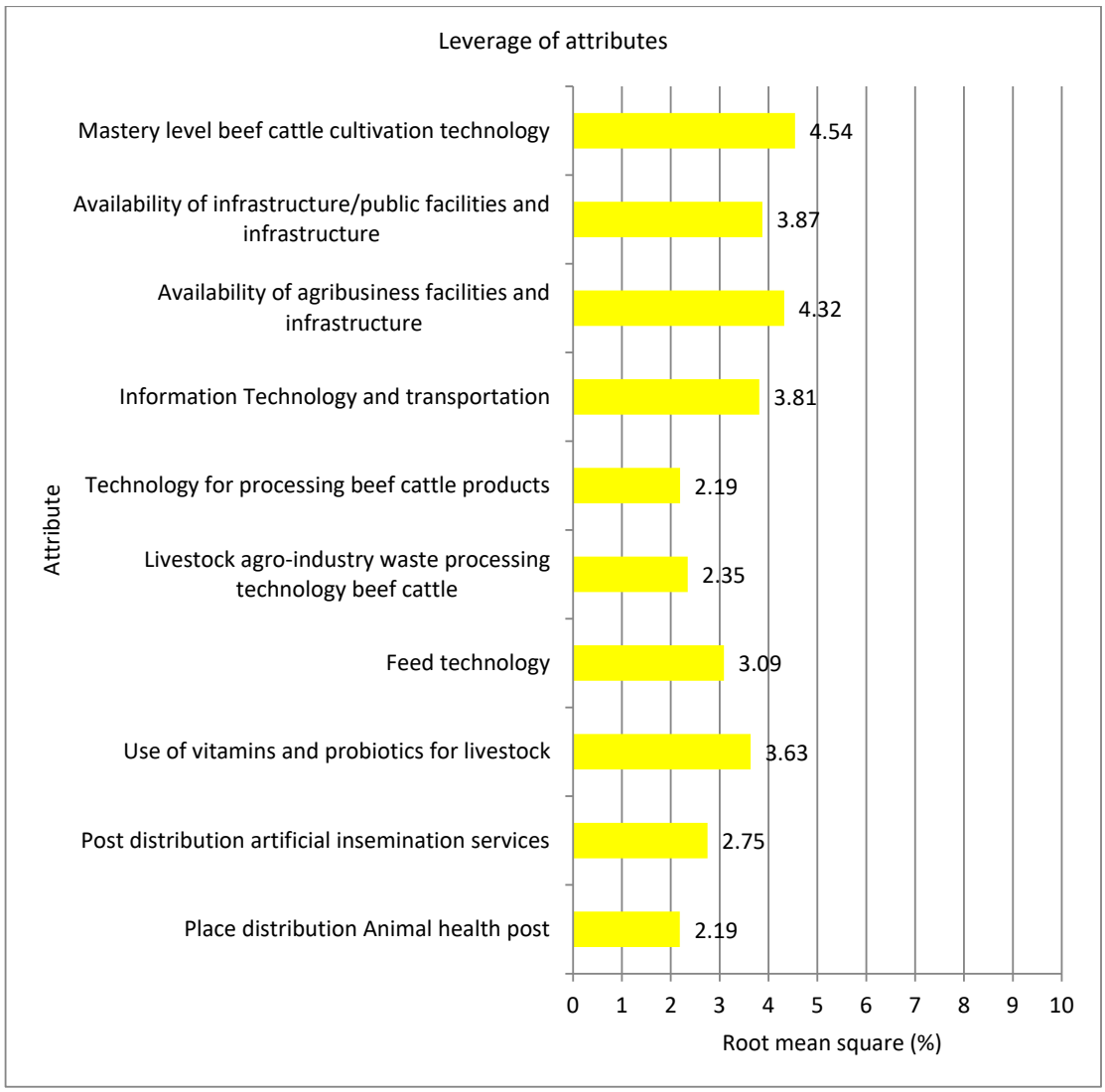


Fig. 5: Leverage attribute for technology and infrastructure dimension

along with developments in information technology and transportation. Mastery of good cultivation technology enables farmers to use optimal livestock management, feeding, and health maintenance practices. The ability of farmers in utilizing technology is closely related to the institutional role attributes of livestock in the institutional dimension. Farmers skilled at using the latest technology are certainly influenced by the role of extension workers in disseminating appropriate technology according to needs. Competent extension services play a crucial role in speeding up the adoption of technological advancements. Farmers may also dramatically boost beef cattle production by implementing modern technology such as livestock health monitoring systems and feed automation. To effectively lower operational costs in beef cattle farming, the implementation of innovative cultivation technology is essential. It can be achieved by enhancing overall production efficiency, optimizing resource utilization, and improving waste management. Terry *et al.* (2021) proposed a strategy aimed at enhancing the efficiency of beef cattle production, emphasizing the importance of management practices, breeding

operations, and the formulation and structure of feed. These strategies must also consider the herd's health and immunity, as well as the need for beef cattle to thrive in a changing environment. Understanding proper cultivation technology can help farmers reduce the risk of disease, accidents, and production failures.Precision, intelligence, and sustainability are the current trends in livestock farming (Zhang *et al.,* 2021). Achieving rapid advancements requires proficiency in intelligent technologies, such as precise feeding mechanisms, environmental regulation, early warning systems for diseases, and remote diagnostic capabilities through the Wearable Internet of Things application. Farmers' ability to master technology must be developed through training. Cattle farmers can no longer raise livestock traditionally and must learn to use technology in the beef cattle business. Breeding and feeding technology must be used to increase production sustainably. Mastery of beef cattle cultivation techniques is essential for ensuring the sustainability of beef cattle and achieving these objectives. Completing waste processing technology for beef cattle farming is essential for ensuring livestock sustainability. Farmers must manage by products or waste generated by beef cattle farming. Cow manure, feed waste, and other waste generated on beef cattle farms can pollute the environment if not properly managed. In arid regions, certain farmers have focused primarily on manures, allowing them to undergo minimal treatment in order to enhance the compost's quality. Following agricultural harvest, farmers utilize different crop byproducts as animal feed, employing cut-and-carry methods to tether and nourish their livestock (Raharjo and Suroyo, 2013). Waste can be processed in a way that does not pollute the surrounding environment by using appropriate waste processing technology, such as anaerobic or aerobic waste treatment systems. The decomposition of cow dung results in the production of methane, a greenhouse gas that can negatively impact the environment. Implementing waste processing technologies can effectively lower greenhouse gas emissions by converting cow dung into a cleaner energy alternative, such as biogas. With the right technology, waste from beef cattle farms can be converted into alternative energy sources such as biogas or biomass energy. This can help reduce reliance on fossil fuels and promote energy sustainability. The improper management of livestock waste poses a significant risk to the environment, leading to potential conflicts with local residents and regulatory bodies. Failure to address waste appropriately may result in legal repercussions, operational limitations, or even the shutdown of farming activities. A lack of equipment for processing beef cow waste can have significant implications for the environment, public health, and the economic sustainability of livestock operations. As a result, Adopting proper waste processing technology is essential for ensuring the sustainability of livestock and the environment. Research conducted by Khoshnevisan *et al.* (2021) indicated that the selection of manure treatment technology needs to be more complex and contentious. A significant number of livestock waste treatment methods concentrate on the solid elements of manure, frequently overlooking the liquid portion that can present environmental hazards. The advancement of technology related to feed provision, particularly in forage, plays a vital role in maintaining sustainable beef cattle production in dry climate areas.

NTT Province is one of Indonesia's driest locations. According to the Kupang City Central Statistics Agency (CSA), the rainy season in NTT lasts only four to five months, i.e., from November to February/ March. Supplying animals with forage year-round is unachievable. To ensure its freshness, forage must be preserved effectively, allowing for its use during times when growth is not possible, particularly in the dry season. To maintain the freshness of forage, appropriate technology that is convenient for beef cattle farmers must be implemented. *Silage* is an animal feed prepared from forage and preserved through fermentation. This method preserves the freshness of forage while maintaining its quality and nutritional content. The quality of silage is fundamentally dependent on the fermentation process that occurs during its production. To improve the quality of forage silage, Ranby and Bakken, (2021) have applied a formic-and propionic acid-based additive to improve grass silage quality, reduce losses, and increase aerobic stability in bunker silos. This study showed that Acid treatment increased dry matter (DM) density by 7% compared with untreated silage. Silage maize is known as the "king of feed" because it is rich in crude protein, carotene, sugar, and other nutrients (Chen *et al.,* 2023). Challenges remain in the preparation of silage material, as

the device frequently encounters blockages in the feeder area. To achieve better energy efficiency, reduce blockages, and enhance the quality of the chopped output, it is crucial to refine the design of the feeder and chopper components of the device. The characteristics of agribusiness facilities and infrastructure play a crucial role in promoting the sustainability of beef cattle farming and should be taken into account. Good agribusiness facilities and infrastructure, such as roads, transportation, storage, and processing facilities, make it easier for farmers to reach markets. Agribusiness facilities determine how beef products are distributed to local, regional, and international markets. Proper processing and marketing infrastructure enables farmers to enhance the value added to cattle products. Farm management must consider facilities for slaughter, packaging, labeling, and efficient distribution approaches. Inadequate or inconsistent transportation infrastructure presents a substantial barrier to the marketing of agricultural products, significantly hindering agricultural development in developing countries. Applications such as the Transport Network Strategic Investment Tool (TraNSIT) developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia, will be beneficial. The tool has been applied to map freight movement for agriculture supply chains in Vietnam (maize, cassava) and Indonesia (rice, cattle) (Higgins *et al.,* 2023). A robust transportation infrastructure, particularly roads, is vital for the effective transport of beef cattle and various livestock products from agricultural sites to market or processing centers. Furthermore, this public facility enables farmers in reaching market areas to acquire animal feed, livestock medications, and necessary equipment. The road infrastructure connecting cattle beef business locations in TTU is mainly unpaved. If the rainy season comes, farmers will find it difficult to sell their cattle, and livestock traders who come to buy at the business location will lower prices to compensate for the difficulties in accessing roads used by traders. Access to transportation infrastructure is critical to the sustainability of beef cattle production. The transportation of animals is a critical aspect of animal production and usage, yet it has been identified as a major factor contributing to stress, which can detrimentally affect economic results and animal health. Welfare and stress evaluations during transportation are commonly assessed through behavioral analysis, metabolic activity, hormonal levels, and pathological assessments. Several corrective measures have been tried to lessen the reaction of animals to transport stress, including preconditioning, vitamin delivery, immunization, high-energy diet feeding, and electrolyte therapy (Bhatt *et al.,* 2021). Information technology and transportation attributes are essential in ensuring the sustainability of cattle farming in the TTU Regency. The integration of information technology allows farmers to improve the management and monitoring of their livestock operations. Through the use of livestock management software, they can keep track of the health and condition of their cows, organize feeding schedules, monitor breeding activities, and manage their inventories more efficiently. This may increase productivity and lower operational costs. By adopting information technology solutions such as health sensors and individual identification, farmers can significantly improve their animal health monitoring practices. This enables the early detection of illnesses and other health-related problems, leading to timely interventions and a decreased likelihood of injuries. Information technology improves the integration of producers, distributors, and consumers in the beef supply chain. Precision livestock farming (PLF) combines modern technology with the fundamentals of information technology. The method has spread to several nations since its inception in 2003, although it has yet to be fully embraced (Morrone *et al.,* 2022). Morrone *et al. (*2022) stated that the introduction of the Internet of Things (IoT) and Industry 4.0 has permitted PLF's continuing improvement and development. The presence of information technology infrastructure has significantly influenced the sustainability of livestock enterprises, particularly in the marketing of livestock products. Traditionally, farmers relied on conventional markets for selling their livestock, but the advent of digital information access has transformed this approach. The existence of information technology has made farmers market their livestock through digital platforms. This has activated marketing activities related to economic dimension attributes, which have an impact on reducing transportation costs for marketing livestock.

Legal and *institutional dimensions*

Cattle farming in drylands has a 77.6% sustainability index, indicating the importance of institutions in

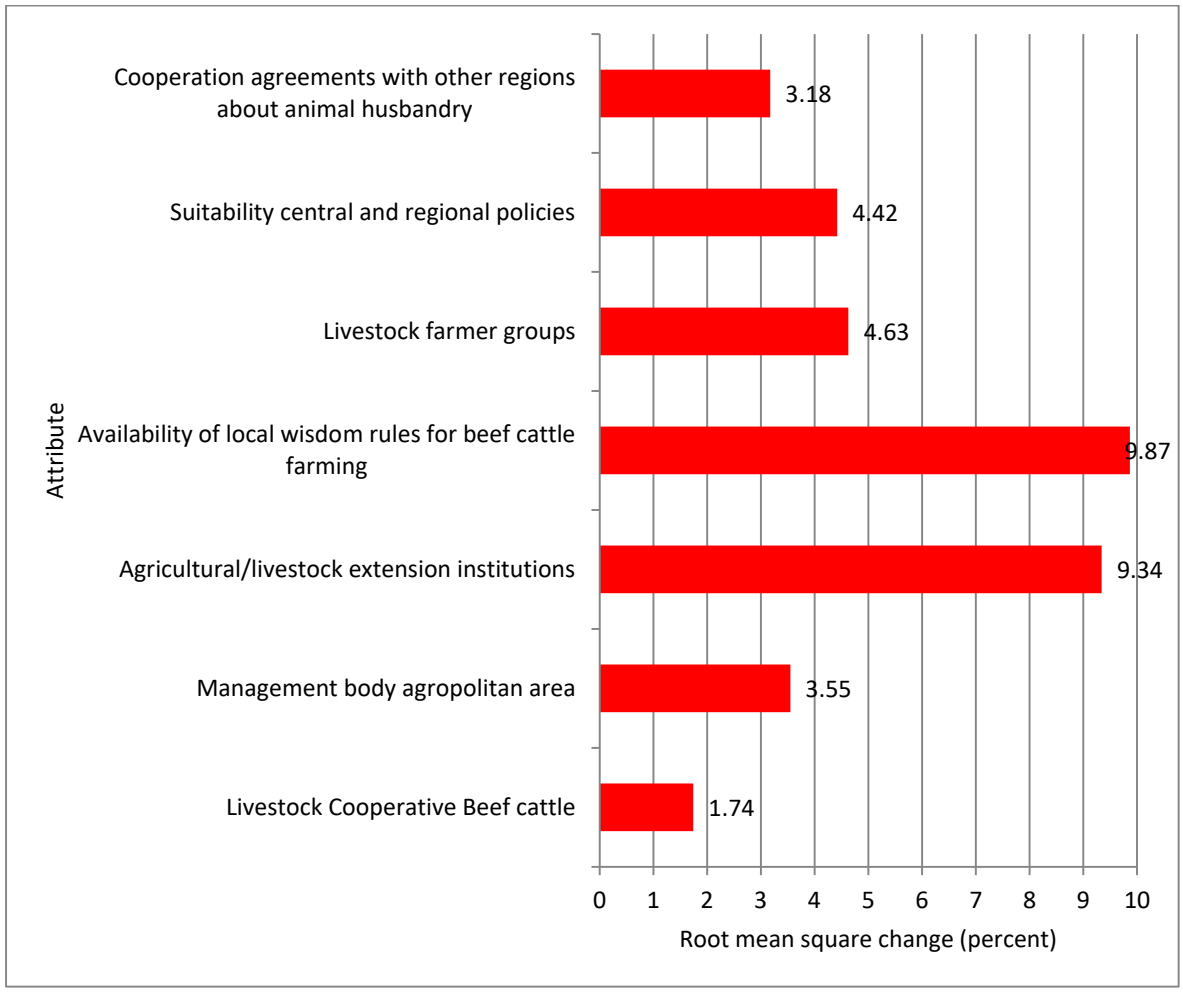


Fig. 6: Leverage attribute for Legal and Institutional technology dimension

promoting efficient, productive, and sustainable growth (Azam *et al.,* 2021). Findings from the analysis indicated that the sustainability index was influenced by various elements, including local wisdom guidelines, organizations dedicated to beef cattle extension, groups of farmers, and the interplay of national and local policies. Fig. 6 below shows the results of the sustainability index and leverage analysis of the legal and institutional components. Local wisdom is crucial for the sustainability of beef cattle in TTU Regency. Communities in the region have developed a deep expertise in managing land and livestock, a tradition of knowledge that has been handed down through the ages. Farmers in TTU use eco-friendly livestock-rearing practices, allowing the cows to develop naturally without much treatment from breeders (Abas *et al.,* 2022). They use local feed that grows all year round. The source of animal feed depends on the friendliness of nature (Firman and Nono, 2021). An additional aspect of local knowledge practiced by farmers involves the utilization of cow dung as a form of organic fertilizer. (Ngongo *et al.,* 2022). Farmers frequently employ organic fertilizers that are cultivated on their properties or designed for horticultural use, and they may also choose to sell these products to create a source of income (Santoso *et al.,* 2023). Farmers also use local herbal herbs for livestock health (Kuralkar and Kuralkar, 2021).

This herb comes from plants that have medicinal properties and have been used for a long time, for

example, papaya leaves for livestock medicine (Osman *et al.,* 2020). Local expertise fosters innovation in the beef cattle market, as seen in the development of Timor cattle that are adapted to withstand dry climatic conditions. By understanding the local ecosystem and livestock needs more deeply, local communities can play a significant role in maintaining environmental balance and livestock welfare, demonstrating a harmonious relationship between humans and their natural environment (Rozaki *et al.,* 2020). The role of livestock extension institutions is vital in enhancing the sustainability of beef cattle within rural communities. They assist farmers in accelerating their socioeconomic development, accessing agricultural knowledge, money, markets, infrastructure, and adopting agricultural advances (Raisa *et al.,* 2020). In TTU Regency, traditional livestock raising is still prevalent, but extension workers provide up-to-date information on best practices including waste management, and environmental conservation (Rohaeni *et al.,* 2024). They deploy advanced technologies for tracking livestock health, assessing animal feed, and managing reproduction. Extension agencies support farmers in mitigating risks and adapting to challenges such as climate change, disease outbreaks, or fluctuations in the market. They provide education and training for farmers to adopt the latest innovations in agriculture. It is essential to expedite the distribution of innovation by implementing comprehensive counseling strategies (Pousga *et al.,* 2022). Counseling must be specific to the context to contribute to the development of the livestock sector (Ahikiriza *et al.,* 2021). The capacity of extension institutions to conduct participatory training with local contextual materials needs strengthening (Ponusamy and Pachaiyappan, 2018). This enables the dissemination of information and experiences, in addition to reinforcing collective solidarity in confronting mutual challenges. Agricultural extension services are provided to small-scale farmers by many parties and through various approaches (Mapiye *et al.,* 2021). Livestock extension workers must function properly and have adequate competence to improve extension both in terms of quality and quantity (Shubeena *et al.,* 2022). According to the insights gathered from the focus group discussion, the primary challenge facing extension services in TTU Regency is the inadequate availability of extension workers within each sub-district. An extension worker has a task for one sub-district, not proportional to the area of work. The implications of this situation will undoubtedly influence the scope of extension activities and diminish the frequency of extension meetings with various groups. Consequently, this will lead to a restricted dissemination of information and a slowed pace of technology adoption within the livestock sector. The process of mentoring and consulting farmers has also become limited, so inadequate access to livestock extension workers and inappropriate information services further reduce farmers' ability to overcome daily challenges and optimize the path to commercialization. This condition has influenced both the environmental and economic aspects significantly. A restricted number of extension workers and the corresponding extension services have a profound impact on farmers' knowledge and skills regarding the implementation of environmentally responsible and efficient livestock farming techniques. One example is the skills of farmers in processing agricultural waste that can be used as animal feed. The lack of extension services provided influences the low abilityIn many developing countries, public extension systems are often burdened by excessive demand, suffer from a deficiency of qualified human resources, and lack the necessary infrastructure, all while witnessing a notable reduction in investment (Mapiye *et al.,* 2021). This could be overcome by increasing farmers' access to information. Extension institutions can make good use of access to information technology, for example through websites, community radios, or mobile phones to disseminate their knowledge and experience (Mustapit *et al.,* 2019). The ability of the extension system to fulfill sustainable agriculture objectives is largely determined by the quality of the extension and consulting services it delivers (Tamsan and Yusriadi, 2022). Livestock extension institutions play an important role in maintaining the sustainability of the beef cattle industry by providing the knowledge, skills, and support needed by farmers to face challenges and improve business performance. Animal husbandry extension institutions must facilitate the establishment of networks between farmers and collaboration with related parties, such as government, universities, industry, and NGOs (Ponusamy and Pachaiyappan, 2018). This enables the dissemination of information and experiences,

which in turn fortifies solidarity in confronting collective challenges. The farmer group attribute significantly impacts the sustainability of the beef cattle farming. Farmer groups are informal institutions in rural areas that foster knowledge and resource sharing among farmers (Raisa *et al.,* 2020). They establish networks of communities to exchange knowledge on optimal practices in livestock management, land stewardship, and sustainable approaches. The introduction of coaching and training programs enables these entities to elevate farmers' expertise in beef cattle management, which in turn fosters superior business management and boosts economic profitability (Abdullah *et al.,* 2019). They can also collaborate with external parties like extension workers or livestock companies to access necessary services and technologies for increased production. This collaboration can lead to increased efficiency, financial profitability (Abdullah, *et al.,* 2019), and the ability to face challenges and obstacles (Raisa *et al.,* 2020). Participation in a farmer group enables farmers to enhance their negotiating power when dealing with various stakeholders, including beef purchasers and suppliers of livestock inputs. This collective approach can lead to improved pricing for their products and greater access to markets, as the formation of these groups is aimed at fostering mutual advantages among the members (Haryadi *et al.,* 2019). The fourth important attribute involves the coherence of policies between national and regional governmental bodies. The success of initiatives aimed at developing beef cattle is largely contingent upon the strategic assistance provided by government policies. The aim for the development of animal farming and health from 2020 to 2024 is to establish a sustainable and competitive agricultural system in Indonesia, which will contribute to the realization of an advanced, autonomous, and contemporary agricultural landscape. The mission is to: 1) increase the availability of quality and sustainable seeds; 2) increase the availability of quality feed on a continuous basis; 3) realize animal health to increase livestock productivity and support public health; 4) improve the safety and quality of animal products and public health; and 5) increase livestock business, processing, and marketing of competitive livestock products. Research findings suggest that the presence of beef cattle plays a vital role in integrated crop-livestock farming systems, contributing to increased productivity and efficiency, all the while upholding the environmental carrying capacity associated with dry land farming practices. The shifting practical agricultural circumstances of farmers, particularly those in dry land areas for the production of peanuts and maize, should garner greater attention from researchers, government institutions, and stakeholders in order to establish sustainable dry land farming systems (Raharjo and Suroyo, 2013). The development of the livestock subsector has a significant impact on rural development and poverty alleviation efforts because the majority of poor people live in the countryside and make a living from farming/farming. To date, the advancement of the farming sub-sector in NTT involves two key roles: 1) Aiming to improve the quality of life for the residents of NTT by increasing agricultural earnings and enhancing community nutrition through better farming techniques and product quality, and 2) contributing to the satisfaction of the national meat requirement by enhancing local farming and agricultural products for consumer communities across different provinces, thereby decreasing the need for foreign exchange in agricultural imports. Concurrently, the local government, via Governor's Decree No. 122 of 2024, has determined a quota allowing for the extraction of 56,260 cattle from NTT. Regulations governing cattle exports must adhere to animal health and transportation standards, which include a ban on the export and slaughter of breeding studs and productive heifers. This figure is lower than pre-2000 allotment, which ranged between 60,000 and 80,000 heads per year. This quota reduction is an attempts to prevent a decline in NTT's cattle population (Priyanto *et al.,* 2020). The consistency of central and regional export quota laws reflects attempts to maintain the NTT cow population, which is a vital step toward sustaining the farming ecosystem's resilience and balance.

CONCLUSION

The analysis and discussion indicate that enhancing the sustainability of beef cattle farming in arid climates necessitates initiatives aimed at improving and optimizing resource potential across four key dimensions. For the environmental dimension, the improvement that needs to be considered is the availability of green fodder throughout the year to meet feed requirements. Implementing a year-round

feed fulfillment strategy can be accomplished by enhancing extension services that provide training to farmers on the production of silage and hay, enabling them to store feed for extended periods. Farmers' feed processing skills must be encouraged to preserve feed when feed production increases during the rainy season. The impact of climate on dry climate significantly affects the sustainability of beef cattle production. The existence of vast pastures, yet lacking in soil fertility, has affected the availability of quality feed provided to beef cattle. The arrangement of grazing fields through the cultivation of quality natural grass can enhance the availability of feed throughout the year. Furthermore, it is crucial to optimize agricultural waste for use as animal feed. From an economic perspective, farmers in dry regions exhibit limited motivation to pursue beef cattle farming as a key source of family income. This indicates that the scale of beef cattle maintenance efforts at the farmer level is not yet optimal in supporting family income. In reality, beef cattle farming is the most resilient endeavor supporting family economies in arid land areas. Another area for improvement within the economic dimension is the expansion of market access, which can be achieved by optimizing the selling price of beef cattle for farmers. In the dimension of technology and infrastructure, the presence of technology and innovation needs to be enhanced, especially in the processing of livestock products that can add value to processed products. So far, farmers have still been selling livestock products in the form of live animals. Currently, animal health posts are not sufficiently established in every district, creating obstacles for farmers seeking veterinary services, especially in managing diseases in beef cattle. In addition, the AI service facilities need to be improved by increasing the number of certified inseminators in each existing sub-district. In terms of legal and institutional dimensions, improvements in the performance of cooperatives in the livestock sector need to be made. The rise in cooperative numbers is facilitated through the enhancement of credit and market services. The government should execute a policy strategy focused on boosting business credit services for livestock farmers, ensuring the availability of low-interest loans. Another policy in optimizing this dimension is increasing the number of extension workers to at least one in each village, including the government's policy of presenting private and independent extension workers to help provide optimal extension services. Improving partnerships with various regions, especially those that import livestock products, is essential for enhancing cooperation. This is done to expand market coverage. The sustainability of beef cattle farming in dry climate has an average sustainability index of 53.09%. This rating comes from the sustainability index values of the environmental dimension at 54.18%, the economic dimension at 45.58%, the technology and infrastructure dimension at 35.15%, and the legal and institutional dimension at 77.46%. In this sustainability index assessment, there are 40 attributes that influence the sustainability of beef cattle. The development plan for beef cattle farming in arid climates must take these attributes into account as they are crucial factors. The outcomes of this study function as a blueprint for establishing collaborative policies that address environmental, economic, technological, and infrastructural factors, in addition to legal and institutional elements.

AUTHOR CONTRIBUTIONS

T. Simamora's role was to conduct literature searches, creating the study plans, supervise on-site data collection, and prepare manuscripts. M N. Rofiq conducted the study design; L. Hutahaean conducted analysis and interpretation; S. Sio contributed to the drafting of the manuscript; R. Hutapea improved the content of the manuscript; D. Irawan critically analyzes the important content value of the manuscript; Suryani produced maps and figures; R. Diastuti contributed to data analysis and provided support; U.N. Thiyas facilitated linking the literature review and data recognition; B.A. Correia drafted the manuscript; L.T. Correia carry out the completion of preparation and refinement of the manuscript as well as degradation of the manuscript

ACKNOWLEDGMENTS

The authors would like to thank the staff involved in the field data collection and the respondents, the cattle breeders, the livestock traders, the heads of the livestock stations in 24 sub-districts and the head of the TTU Livestock Service who gave permission for this Conduct study. The Sustainable Production Systems and Life Cycle Assessment Research Center, the National Research and Innovation Agency and Institute for Research and Community

Service, University of Timor supported the smooth implementation of this study. This study received no specific financial support from funding agencies in the public, commercial or not-for-profit sectors.

CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

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ABBREVIATIONS

%	Percent
°C	Degree Celsius
AI	Artificial insemination
CSA	Central Statistics Agency (CSA)
CSIRO	Commonwealth Scientific and Industrial Research Organization
DM	Dry matter
FGDs	Focus group discussions
Fig	Figure
IoT	Internet of Things
GDP	Gross domestic product
GRDP	Gross regional domestic product
Km²	Square kilometer
mm	Millimeter
MDS	Multidimensional Scalling
NTT	Nusa Tenggara Timur
PLF	Precision livestock farming
Rap-dryclimate	Rapid appraisal for dryclimate analysis tool
Rap-Pforest	Rapid appraisal for private-forestry analysis tool
Rap- SAPOT	Rapid appraisal of beef cattle
RMS	Root mean square
TraNSIT	Transport Network Strategic Investment Tool
TC	Timor cattle
TTU	Timor Tengah Utara

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AUTHOR (S) BIOSKETCHES

Simamora, T., Ph.D., Lecturer, [1]Animal Husbandry Study Program, Faculty of Agriculture, Science and Health, Timor University; Post Doctoral, [2]Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia.
• Email: *turesimamora@unimor.ac.id*
• ORCID: 0000-0001-8331-5590
• Web of Science Researcher ID: JGL-8414-2023
• Scopus Author ID: 58209128900
• Homepage: https://www.unimor.ac.id/

Rofiq, M.N., Ph.D**.,** Researcher, Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia.
• Email: *mnas001@brin.go.id*
• ORCID: 0000-0002-4632-9376
• Web of Science Researcher ID: AAZ-6409-2020
• Scopus Author ID: 57221967761
• Homepage: https://brin.go.id/

Hutahaean, L., M.S., Senior Researcher, Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia.
• Email: *lint001@brin.go.id*
• ORCID: 0000-0002-8437-5605
• Web of Science Researcher ID: NA
• Scopus Author ID:57225173715
• Homepage: https://brin.go.id/

AUTHOR (S) BIOSKETCHES

Sio, S., Ph.D., Lecturer, Animal Husbandry Study Program, Faculty of Agriculture, Science and Health, Timor University.
• Email: *stefsio67@gmail.com*
• ORCID: 0000-0002-3287-6328
• Web of Science Researcher ID: NA
• Scopus Author ID: 57506571400
• Homepage: https://www.unimor.ac.id/

Hutapea, R., M.Eng., Senior Researcher, Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia.
• Email: *ramo001@brin.go.id*
• ORCID: 0009-0001-0572-8071
• Web of Science Researcher ID: HSA-6979-2023
• Scopus Author ID: 58717129100
• Homepage: https://brin.go.id/

Irawan, D., M.Sc., Researcher at Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia.
• Email: *dody001@brin.go.id*
• ORCID: 0000-0003-1948-4415
• Web of Science Researcher ID: HRA-9467-2023
• Scopus Author ID: NA
• Homepage: https://brin.go.id/

Suryani, S.Si., Researcher, Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia.
• Email : *sury021@brin.go.id*
• ORCID: 0009-0005-6072-8911
• Web of Science Researcher ID: JXN-4818-2024
• Scopus Author ID: NA
• Homepage: https://brin.go.id/

Diastuti, R., M.Si**.,** Senior Researcher, Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia.
• Email: *renn003@brin.go.id*
• ORCID: 0009-0000-6874-8195
• Web of Science Researcher ID: NA
• Scopus Author ID: NA
• Homepage: https://brin.go.id/

Thiyas, U.N, S.Si**,** Researcher at Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Indonesia.
• Email: *ulfa002@brin.go.id*
• ORCID: 0009-0003-8517-9838
• Web of Science Researcher ID: JXN-6131-2024
• Scopus Author ID: -
• Homepage: https://brin.go.id/

Correia, B.A, Ph.D., Department of Agricultural, Faculty of Agriculture, Timor Lorosa'e National University, Dili, Democratic Republic of Timor-Leste.
• Email: *brigida.correia64@gmail.com*
• ORCID: 0009-0002-0500-3043
• Web of Science Researcher ID: NA
• Scopus Author ID: NA
• Homepage: https://untl.edu.tl/pt/

Correia, L.T, Ph.D., Department of Agricultural, Faculty of Agriculture, Timor Lorosa'e National University, Dili, Democratic Republic of Timor-Leste.
• Email: *correia.ligia3@gmail.com*
• ORCID: 0009-0008-3406-1991
• Web of Science Researcher ID: NA
• Scopus Author ID: NA
• Homepage: https://untl.edu.tl/pt/

HOW TO CITE THIS ARTICLE

Simamora, T.; Rofiq, M.N.; Hutahaean, L.; Sio, S.; Hutapea, R; Irawan, D.; Suryani.; Diastuti, R.; Thiyas U.N.; Coreia B.A.; Correia L.T. (2024). Sustainability index for eco-friendly cattle farming in dry climate regions. Global J. Environ. Sci. Manage., 10(SI): 279-302.

DOI: 10.22034/gjesm.2024.10.SI.18

URL: https://www.gjesm.net/article_715766.html