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Spatial difference and economic resistance of smallholder beef cattle farming in the seasonally dry tropics of Indonesia

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Abstract. *Fathurohman F, Safitri LS, Vinanda G, Khairad M, Fortuna PED, Utami IRP, Indrianingsih RS. 2026. Spatial difference and economic resistance of smallholder beef cattle farming in the seasonally dry tropics of Indonesia. Intl J Trop Drylands 10 (1): t100103. https://doi.org/10.13057/tropdrylands/t100103.* Beef farming in seasonally dry tropics under Oldeman D3/E climatic conditions is characterized by a long dry season (5-7 months) with little or no precipitation (<100 mm), leading to extreme feed shortage and socio-economic exposure. Therefore, this study aims to evaluate the ecological carrying capacity of agricultural by-products and the economic resilience of smallholder beef cattle systems in Subang District, Indonesia. During the study procedures, regional agronomic data were combined with socio-economic data from 150 farmers. These farmers were classified as "Conventional" and "Optimized" feeding systems depending on the use of processed crop residues. Based on spatial analysis, there was a huge potential for agricultural residues to be utilized as alternative ruminant feed (more than 1 million tons of dry matter per year). However, the available feed resources were not uniformly distributed, resulting in a geographical isolation of the forage-deficient livestock centers in the south from the high-production lowlands in the north. From an economic perspective, the "Optimized" system (mechanical chopping and local fermentation) showed better resilience, according to the descriptive deterministic modelling. This adaptability was reflected in increased daily profit margins (USD 0.70 vs USD 0.10 per animal unit) and a reduction in daily labor hours by 2.5 hours from a distant foraging. The region's feed insecurity was largely caused by inefficiencies in the distribution of resources rather than a biological deficit. Improving the ability of smallholders to survive long droughts could be achieved by implementing intelligent policy changes with regard to inter-zonal biomass mobilization and on-farm processing facilities. These interventions are key to help close the gap of geography and to promote the socio-ecological sustainability in a long-term perspective in forage-constrained environments.

Keywords: Circular bioeconomy, climate adaptation, dry season vulnerability, feed security, smallholder livestock

Abbreviations: AU: Animal Unit, BPS: Statistics Indonesia, CC: Carrying Capacity, DM: Dry Matter, R/C: Revenue-Cost, RPR: Residue-to-Product Ratio

INTRODUCTION

Smallholder farmers in the seasonally dry tropics often use integrated crop-livestock systems on a large proportion of the world's agricultural area (Thornton et al. 2009; Herrero et al. 2013). In such systems, mixed farming is an integral part of the risk management toolbox that can be used to reduce the effect of climate variability. In Indonesia, beef cattle production serves as a very important socio-economic safety net. It can also be considered as an asset that can be liquidated when there are unplanned and urgent expenditures or a shortfall in cash income. Beef cattle production is highly sensitive to monsoonal rainfall patterns and water deficits specifically during the prolonged dry seasons (east monsoon) (Widiati and Widi 2016; Agus and Widi 2018). Therefore, these transitional ecosystems are inherently restricted by the intermittent high variability of rainfall and long dry seasons, reducing the amount of primary biomass production and natural forage available (de Haan 2016; Godde et al. 2021). The climatic conditions result in frequent seasonal feed shortages, posing a direct challenge to the viability of ruminant production, especially for small-scale farms with low capital input. In addition to a decrease in Carrying Capacity (CC) when pastures are over-dry, the quality of available forage also decreases. This double reduction forces farmers to buy their concentrated feeds at high prices or to go increasingly farther to collect wild grasses (Widiati and Widi 2016; Arifah et al. 2022). Consequently, the price of production and vulnerability of the household increase.

According to previous studies, agricultural by-products such as rice straw (*Oryza sativa* L.), corn stover (*Zea mays* L.), and legume haulms (*Arachis hypogaea* L. and *Manihot esculenta* Crantz) can be used as a valid adaptive measure in the context of circular bioeconomy to address environmental challenges (Valbuena et al. 2019; Balehegn et al. 2020; Ünlü et al. 2022). The valorization of these underutilized residues can lead to a more sustainable nutrient cycle for the farmers, which reduces waste and increases resource efficiency. Crop residues can be a useful ecological buffer to minimize the grazing pressure on sensitive uplands, while also enabling agricultural waste to be processed into animal feed. Optimization of local by-products can enhance socio-economic resilience by lowering the use of volatile external inputs. This helps farming communities to sustain their herd productivity and to effectively manage fluctuations in the ratio of income to cost during dry seasons (Cortner et al. 2019; Valbuena et al. 2019). The development of a viable crop-livestock system is crucial to the future of ecologically and economically sustainable seasonally dry farming systems.

Although this nexus is important, there is limited literature that discusses the evaluation of biological feed and the economic feasibility analysis within seasonally dry tropical livestock systems in Indonesia. Previous studies have focused on the technical CC from the waste production of the region (Syamsu et al. 2003; Dumont et al. 2019), as well as the socio-economic aspects and income generation of smallholder systems (Budisatria et al. 2010; Widiati and Widi 2016). However, these traditional methods do not take into account the spatial friction and logistical challenges that prevent local surpluses from reaching areas with deficits. Integrated studies that directly relate the spatial distribution of agricultural biomass with farm-level economic resilience are lacking. Therefore, this current study builds upon existing literature by integrating biomass CC mapping for sub-districts, a spatial mismatch assessment, and comparative farm-level economic metrics. It also integrates the regional data's scalability with the capability of smallholders to transport biomass efficiently, considering the logistical and socio-economic constraints.

The Subang District of West Java, Indonesia, is an appropriate setting for this spatial-economic approach. The area is characterized by Oldeman climate types D3 and E, both of which are seasonally dry tropical constraints with 5-7 months of a dry season and monthly rainfall of less than 100 mm (Oldeman 1975; Oldeman et al. 1980). Subang is geographically divided into 3 different topographical zones, namely the southern side consisting of mountains, the central side with rolling hills, and the northern side with lowlands along the coast and intensive irrigated agriculture (Rachmita et al. 2021). The area also has a unique physical geography, which results in large surpluses of residues from the northern plains and a forage shortage in the southern uplands. This causes a "resource-demand" paradox that exists on a local scale, as the livestock centers in one zone cannot easily access the biological resources of another zone. Therefore, this study aims to examine the ecological CC of agricultural by-products and the economic resilience at the farm level. Resilience is expressed in terms of some measurements, such as Average Daily Gain (ADG), reduction of production cost, R/C ratio, and daily profit margins. The indicators are applied to assess smallholder beef cattle farming system in the conditions of scarcity of seasonal feed in the tropical seasonally dry tropics of Subang, Indonesia.

MATERIALS AND METHODS

Study area

This study was conducted in Subang District, West Java, Indonesia (6°11′ to 6°49′S and 107°31′ to 107°54′E) (Figure 1). From the topographic point of view, the area was divided into 3 zones, namely coastal lowland (0 to 50 m asl), undulating hilly terrain (50 to 500 m asl), and mountainous region (500 to 1,500 m asl). Based on scientific analysis, Subang District was classified as a seasonally dry tropical environment due to the nature of its rainfall pattern and water deficit in the rainy season. The study area had an annual rainfall of about 1850 mm, calculated based on a 10-year average of local climatic data (2016-2025), and had a well-defined dry season (5-7 months) during which monthly rainfall was below 100 mm. According to the Oldeman climate classification (Oldeman 1975; Oldeman et al. 1980), the area was mostly classified as D3 and E with limited consecutive wet months and high moisture stress, which was the main reason for forage scarcity during the dry season.

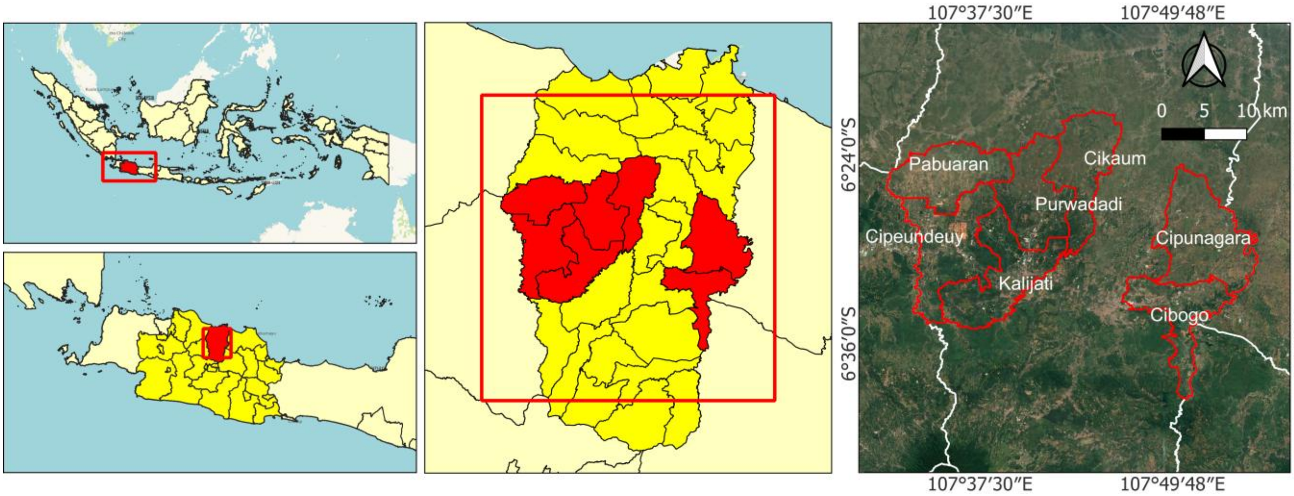

Figure 1. Study location showing the seven selected sub-districts in Subang District, West Java, Indonesia

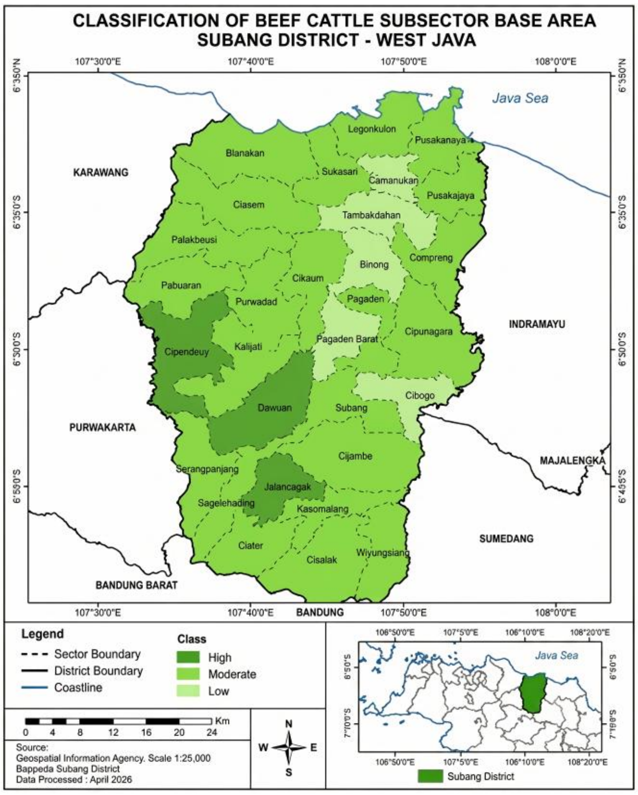

Figure 2. Spatial distribution and classification of beef cattle subsector base areas in Subang District, West Java, Indonesia. Base areas are identified using the Location Quotient (LQ) method based on 2021-2025 livestock population data. Data source: Regional Development Planning Agency of Subang District (Badan Perencanaan Pembangunan Daerah (Bappeda) 2025) and Subang Livestock Agency (2025), processed by authors (2026)

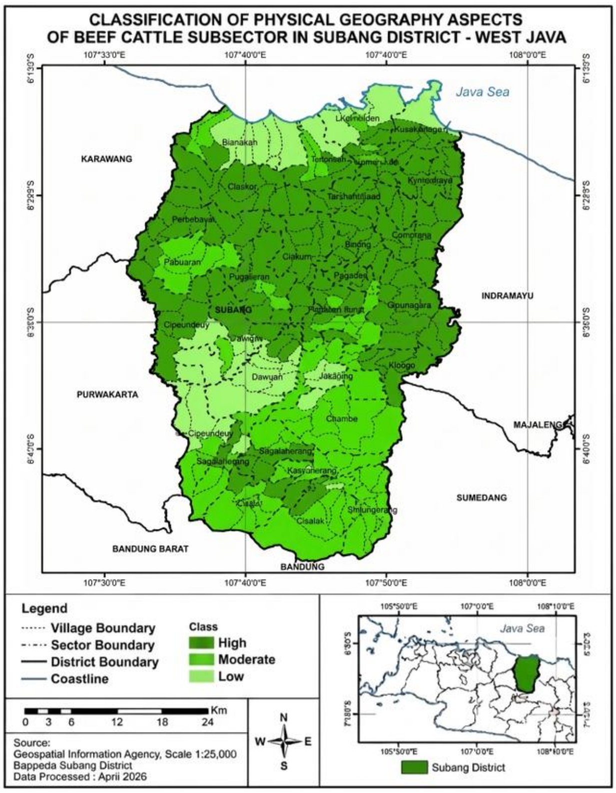

Figure 3. Topographical zoning of Subang District, West Java, Indonesia (Northern Lowlands, Central Hills, and Southern Highlands). The digital elevation model (DEM) illustrates the transition from intensive irrigated lowlands (0-50 m asl) to mountainous livestock centers (500-1,500 m asl). Data source: Regional Development Planning Agency (Bappeda) of Subang District (2021), Rachmita et al. (2021), Geospatial Information Agency (BIG) (2025), and processed by authors (2026)

Biomass production potential was determined by these topographical differences, as shown in Figure 3. The base areas of beef cattle identified in Figure 2 were based on Location Quotient (LQ), calculated from 2021 to 2025 population data. This study examined the spatial mismatch between forage-poor livestock centers (undulating hills and mountainous terrain in the central and southern uplands) and feed-rich centers (intensive irrigated lowlands in the north) by overlaying Figures 2 and 3. This geographic juxtaposition pointed to a paradoxical structure, such as the southern high elevation mountainous regions (where many primary livestock bases are found in the high-LQ areas of Figure 2), which was physically removed from the vast surplus of crop residues produced in the low elevation northern coastal plains. This spatial configuration was analyzed to map the geographic baseline of feed availability, evaluating how topographical variations and geographic distance from the lowland production centers relate to the localized forage security of smallholder systems. The visualization of the spatial data was made using Quantum Geographic Information System (QGIS) software (v.3.44.7) with data obtained from the Subang Livestock Agency and the Indonesian Geospatial Information Agency (BIG).

Procedures

Data collection

Primary socio-economic data were collected through a structured survey face-to-face, in-person interviews conducted by trained enumerators from September to November 2025. A total of 150 smallholder beef cattle farmers were selected via a multi-stage purposive sampling framework. Stage 1 selected Subang District as a representative seasonally dry tropical region. The central and southern zones were targeted in stage 2 because of their high cattle density and vulnerability of forage during this season. A farmer-level survey was not carried out in the north zone, as this area was mainly a biomass-surplus area with a very low density of beef cattle and was irrelevant for the analysis of farm-level adaptation to acute feed scarcity. A total of 7 sub-districts were selected for stage 3, including Cibogo, Cipunagara, Cikaum, Purwadadi, Cipeundeuy, Pabuaran, and Kalijati. Lastly, respondents were grouped according to their feeding management in Stage 4.

During the interviews, respondents were explicitly instructed to consider and recall their operational practices, input costs, and labor allocations specifically corresponding to the peak dry season of 2025 (the preceding 6-month dry period under moisture stress). To minimize social desirability bias and ensure data integrity, interviews were conducted individually on-site at the farmers' homes or corrals to guarantee privacy and anonymity. Furthermore, economic and income questions were framed neutrally around tangible physical quantities (exact kilograms of feed bought, daily hours spent in transit) rather than direct wealth questioning, and self-reported parameters were cross-verified through physical feed inventory checks and visual Body Condition Scoring (BCS) of the cattle herd.

The structured survey instrument comprised five distinct thematic modules: (i) household socioeconomic and demographic characteristics, (ii) herd structures and seasonal population dynamics, (iii) daily seasonal feed consumption patterns (quantities of fresh forage, processed crop residues, and concentrates used), (iv) seasonal labor time allocation and transit distances for feeding activities, and (v) explicit operational cash expenditures and revenue streams from livestock sales. Before the full implementation, the survey instrument was pre-tested and validated with 15 representative farmers to ensure conceptual clarity and cultural appropriateness. Respondent characteristics such as age, education, experience, and herd size were collected in the survey. This was able to capture farm economic indicators like input costs and revenue streams. The survey also included details of labor allocation per day (hours/day) and distance travelled to collect feed (km) to assess labor efficiency. To preserve data integrity, extreme outlier data points in the cost and labor data were identified and addressed using the Interquartile Range (IQR) method. In particular, the pricing of the units was compared with the Livestock Production Cost Standards 2024 (Subang Agriculture Agency 2024). Any value that was outside of the 20% margin was followed up using either a respondent or a local market price check. This triangulation, as mentioned, helped to make sure that the data did not suffer from recall bias and extreme outliers that could not be verified.

In this study, there were 2 groups of farmers, namely 'Conventional' (using natural grass/commercial concentrates) and ‘Optimized’ (> 30% of agricultural by-products were used in the daily Dry Matter intake). The 30% threshold is derived from local feed trials in smallholder systems in Southeast Asia that have shown that at least 30% of the Dry Matter (DM) intake must be replaced to substantially change the efficiency of the rumen fermentation system and reduce reliance on high-cost commercial concentrates (Syamsu et al. 2003; Wanapat 2009). Optimization included mechanical chopping and urea-treatment or fermentation. Secondary data were obtained from Badan Pusat Statistik (BPS) Subang (2025). To account for annual fluctuations in climate and agricultural production, the secondary data regarding crop yields and livestock populations used for regional macro-level mapping were collected and averaged over a five-year period (2021-2025). The group size difference (102 conventional vs. 48 optimized) was consistent with the current rate of adoption of residue-processing technology. To minimize the risk of selection bias, the homogeneity of socio-economic profiles of both groups was confirmed. As given in Table 1, the detailed distribution of respondents was given.

Residue conversion factor

The raw agricultural harvest data were not used directly because of biological inaccuracies that had to be taken into account for the feed evaluation. The total value of the agricultural by-products (crop residues) needed to be expressed in Dry Matter (DM) terms. A standardized Residue-to-Product Ratios (RPR) as well as DM percentages were used in this procedure. These conversions have been carried out using the methodological framework based on the international tropical animal nutrition literature (Dumont et al. 2019; Balehegn et al. 2020; Ünlü et al. 2022). Available forage biomass from each crop type was estimated by the conversion factors listed in Table 2.

The numerical RPR and DM values contained in Table 2 were only selected from the results of national baseline studies standardized for tropical agricultural systems in Indonesia (Syamsu et al. 2003), while the theoretical basis was based on international literature. These coefficients were quite suitable for Subang District, because the dominant types of crops were represented in the area (lowland paddy and hybrid corn) and the traditional methods of post-harvest processing throughout West Java.

Table 2. Conversion factors for agricultural by-products (RPR and DM)

Crop type	By-product type	RPR	DM (%)
Paddy	Rice straw	1.0	86.0
Maize	Corn stover	2.0	40.0
Cassava	Cassava leaves	0.1	25.0
Sweet potato	Sweet potato vines	0.3	18.0
Peanut	Peanut haulms	1.2	22.0

Note: The conceptual framework is on par with the international feed evaluations (Dumont et al. 2019; Ünlü et al. 2022), and the numerical coefficient is on par with the national baseline of Indonesia (Syamsu et al. 2003)

Table 1. Distribution of surveyed respondents by sub-district and feeding system (n = 150)

Topographical zone	Sub-district	Conventional system (n)	Optimized system (n)	Total respondents
Central buffer	Cipunagara	14	11	25
	Cibogo	14	8	22
	Cikaum	14	8	22
	Purwadadi	15	7	22
	Cipeundeuy	14	5	19
	Pabuaran	15	5	20
	Kalijati	16	4	20
Total		102	48	150

Note: Conventional system refers to traditional grazing or feeding practices without specific nutritional intervention; Optimized system was defined as the use of formulated rations or better forage management. n: Number of respondents. Source: Primary data (2025)

Data analysis

Ecological CC

The feed resource was evaluated based on a deterministic quantitative approach and was adapted from the standard feed inventory methods (Makkar 2016; Dumont et al. 2019). First, total biomass production (in DM) was calculated, using Equation (1).

$$BP_{DM} = \sum_{i=1}^{n} (P_i \times R_i \times DM_i) \quad [1]$$

Where, the values used in the calculations are as follows: BP_{DM} = 2 x 2 x 2 x 2 x 6.8 x 1000 = 112,000 tons/year of total Biomass Production in Dry Matter, P_i: harvested production of the crop i (tons/year). The residue-to-crop ratio for crop i, (R_i, dimensionless) is the ratio of the amount of residue (in kg/ha) to the amount of crop (in kg/ha), the dry matter percentages of crop i's residues (DM_i, %).

To determine actual feed availability, this study applied a utilization scenario of 50 to 70% of the calculated BPDM. Agronomically, retaining 30 to 50% of residues was essential for soil nutrient cycling. Practically, 100% extraction was unfeasible due to collection inefficiencies and competing uses. Potential CC was determined based on a standard annual requirement of 2.28 tons of DM per 250 kg AU. Subsequently, the potential CC was determined based on this requirement, as expressed in Equation (2).

$$\text{Potential CC} = \frac{BP_{DM}}{2.28} \quad [2]$$

Where, Potential CC: Potential Carrying Capacity (Animal Units / AU), The total biomass production in dry matter (BP_{DM}) for a particular species is calculated from Equation (1); 2.28: The standard annual dry matter requirement per AU (tons DM/year/AU)

Animal unit conversion

Raw cattle head numbers (27,119) were standardized as AU to consider the different DM requirements for cattle. Attitudes to stocking rates could change from season to season as a result of tactical destocking or selling cattle during the driest periods (BPS Subang 2025; Subang Livestock Agency 2025). The conversion was made using a standard coefficient that has been determined by the Directorate General of Livestock and Animal Health Services (2020) in Indonesia. Table 3 provides the demographic structure that was used when calculating this, along with the age group weights. These specific coefficients, when used with the herd structure for the region, provided a total feed requirement of 23,471.5 AU (rounded to 23,500 AU for regional analysis) from 27,119 heads of stock.

Spatial analysis

The Carrying Capacity Index (CCI = Potential CC/P) was used for sub-district-level mapping of results. Sub-districts were classified as: Surplus (CCI > 1.2): Feed resources exceeded demand by more than 20%, showing a high potential for biomass export, equilibrium (0.8 ≤ CCI ≤ 1.2): Feed resources were marginally sufficient to meet current demand, deficit (CCI < 0.8): Insufficient biomass, requiring external mobilization.

These thresholds were grounded in regional feed security standards to account for logistical losses, seasonal variability, and uncollected biomass (Syamsu et al. 2003; Makkar 2016). The 20% safety margin (CCI > 1.2) was especially critical in tropical drylands to protect against variability in crop production in long dry seasons. The individual performance of the 7 sub-districts surveyed (Cibogo, Cipunagara, Cikaum, Purwadadi, Cipeundeuy, Pabuaran, Kalijati) was analyzed to pinpoint the local spatial mismatches, while the main results (Table 7) summarized zonal shares.

Socio-economic resilience and statistical analysis

The economic viability was assessed by the ratio of the revenues (R) to the costs (C). Revenue (R) was determined as the imputed live weight value gained over a typical 180-day fattening period (Equation 3). The ADG values for both Conventional and Optimized systems were established at 0.45 kg/day and 0.55 kg/day, respectively. These parameters were obtained from the official baseline database of the Livestock and Animal Health Agency of Subang District, serving as empirical regional standards for beef cattle productivity in the economic model. These were calculated from the farmer's weight estimates made seasonally and visual Body Condition Scoring (BCS) during field surveys and compared with the Subang Livestock Agency's regional growth standards. The economic model was based on a descriptive-deterministic budget and identified and quantified the exact profit margin per animal unit at baseline. This approach of baseline validation was based on an empirical process of parameterization of the model, local institutional data (Subang Agriculture Agency 2024), and not on stochastic inferential frameworks.

$$R = (ADG \times t \times P_{lw}) \quad [3]$$

Where, R: Gross revenue from weight gain, USD, ADG: Average daily gain of either Conventional (0.45 kg/day) or Optimized (0.55 kg/day), t: Fattening duration (180 days), and Plw: Average live-weight price (USD 3.44/kg). The ADG values are practical working estimates calculated by triangulation of farmer-reported estimates, visual BCS, and regional growth benchmarks.

Table 3. Demographic structure and Animal Unit (AU) conversion of the beef cattle population in Subang District, West Java, Indonesia

Category	Age (years)	AU coefficient	Population (heads)	Proportion (%)	Total (AU)
Adult cattle	> 2	1	21,180	78.10%	21,180.00
Young cattle	1 - 2	0.5	3,227	11.90%	1,613.50
Calves	< 1	0.25	2,712	10.00%	678
Total			27,119	100%	23,471.50

Note: AU Coefficients were based on Ditjen PKH standards (1 AU = 250 kg adult animal). Population data was a composite from BPS Subang (2025) and Subang Livestock Agency (2025). Total AU was rounded for regional analysis

The R/C ratio was then determined as the total revenues over the total production expenses (feed, labor, and veterinary services). This method ensured that the economic resilience of each of the systems was compared to real market-driven prices and not just to standardized estimates (Cortner et al. 2019).

The main economic indicators were analyzed through a descriptive-deterministic model, while an inferential statistical validation was performed to reinforce the analysis. Prior to inferential testing, continuous economic data (daily input costs, revenue, profit margins, and labor hours) were subjected to the Shapiro-Wilk test to evaluate the assumption of normal distribution. Because the dataset exhibited mild skewness and featured unequal group sizes (102 conventional vs. 48 optimized), the non-parametric Mann-Whitney U test was performed using SPSS software as a robust alternative to compare the statistical differences between the two independent feeding groups. Statistical significance was established at a 95% confidence level ($\alpha = 0.05$).

Economic valuation assumptions

Standardization and assumptions were adopted for the economic analysis in order to ease the process of its reproducibility (Table 4). The Indonesian Rupiah (IDR) value of all economic values in this study was converted to United States Dollar (USD) with a fixed rate of IDR 16,000/ USD 1. The opportunity cost approach (shadow pricing) was used to value forage and labor costs to provide a realistic assessment of smallholder systems, in which labor may be supplied by family members, and forage could be taken for free. The labor wage was based on the Subang District Minimum Wage (UMK), which was converted into USD 0.78 per hour.

The parameters given in Table 4 were incorporated in the economic models, and the daily operational costs and revenue were quantified. The price range information in the markets is provided in Table 4, and the fixed daily costs used in the evaluation were calculated as the mean of the price ranges. A comprehensive economic assessment was carried out by applying a labor and forage opportunity-cost approach (shadow pricing). Due to the majority of labor being family labor and forage being often collected for free, the costs were calculated by multiplying total time expenditure for feeding activities (harvest, process, and distribute) by the agricultural wage rate (USD 0.78/hour) in the area.

Biological parameters, such as mean live weight and fattening cycles, were collected from farmer interviews and considered to be a proxy for the biological parameters rather than a precise physiological measurement. To reduce recall bias, these values were validated with Livestock Production Cost Standards (Subang Agriculture Agency 2024) to ensure that they are within realistic local growth ranges. Economic metrics that resulted were first modeled on a deterministic basis and then tested inferentially to evaluate significant differences in economic returns between the conventional and optimized feeding systems. Prior to the inferential analysis, data normality was verified using the Shapiro-Wilk test. Because the continuous economic data did not strictly adhere to a normal distribution and the two independent groups had unequal sample sizes (conventional $n = 102$; optimized $n = 48$), the non-parametric Mann-Whitney U test was performed to ensure statistical robustness.

RESULTS AND DISCUSSION

Socio-economic profiles and ecological CC of agricultural by-products

Table 5 shows that the socio-economic characteristics of the 150 farmers surveyed indicate a stable and experienced workforce that could form a good foundation for livestock management in Subang. Demographically, the smallholder beef cattle sector is predominantly male-operated (88%). The surveyed farmers are generally within a mature demographic bracket (35-55 years) and possess substantial practical experience (10-20 years), indicating a strong reliance on established traditional husbandry practices. Although the group sizes are unbalanced (conventional $n = 102$; optimized $n = 48$), Table 5 shows that there is a demographic and asset homogeneity between the 2 groups, with similar baseline herd sizes (3.2 - 3.5 AU) and similar education levels.

Table 4. Breakdown of economic variables and assumptions (Input/Output parameters)

Variable	Unit	Value/ assumption	Data source/rationale
Input parameters:			
Forage (natural grass) cost	USD/kg	0.025 - 0.038	Local opportunity cost of labor to gather.
Rice straw (unprocessed)	USD/kg	0.012 - 0.022	Farm-gate price at harvest time.
Rice straw (fermented/treated)	USD/kg	0.031 - 0.047	Includes labor for processing, and urea / probiotics cost.
Commercial concentrate	USD/kg	0.281 - 0.325	Market price at Subang (Average 2025).
Labor wage (imputed)	USD/hour	0.78	It is based on minimum wage of Subang District (UMK).
Output parameters:			
Mean live-weight price	USD/kg	3.44	Average price of local traders/slaughterhouses.
Exchange rate	IDR/USD	16,000	International reporting standard rate.
Fattening period	Days	180	Normal fattening cycle for smallholders.

Note: All values are in US dollars and at the exchange rate of 1 USD = 16,000 IDR. Labor and forage costs are imputed using opportunity costs of production in the region. The validation of unit prices was carried out based on the Livestock Production Cost Standards of Subang District, West Java, Indonesia, for the year 2024 (Subang Agriculture Agency 2024)

Table 6. Potential of agricultural by-products and DM CC in Subang District, West Java, Indonesia (Average 2021-2025)

Crop type	Average production (tons/year)	Total DM (tons/year)	Potential CC (AU/year)*
Paddy	1,125,400	967,844	424,493
Maize	42,500	34,000	14,912
Cassava	28,300	707	310
Sweet potato	8,400	453	199
Peanut	3,100	818	358
Total regional available		1,003,822	440,272
Realistic range (50-70% utilization)			220,136 - 308,190

Note: *Calculated based on 1 AU = 2.28 tons DM/year. Realistic range assumes 30-50% loss due to collection inefficiency and competing uses. Nutritional constraints of paddy residue are discussed in the "Biomass potential and the nutritional bottleneck" sub-section

Table 5. Socio-economic profile of smallholder beef cattle farmers (*n* = 150)

Demographic variables	Category	Frequency (*n*)	Percentage (%)
Gender	Male	132	88.00
	Female	18	12.00
Age	< 35 years	22	14.67
	35 - 55 years	93	62.00
	> 55 years	35	23.33
Education Level	Primary School (SD)	58	38.67
	Junior High School (SMP)	42	28.00
	Senior High School (SMA)	44	29.33
	Higher Education (Diploma / Degree)	6	4.00
Farming Experience	< 10 years	34	22.67
	10 - 20 years	78	52.00
	> 20 years	38	25.33
Herd Size (Animal Units/AU)	1.0 - 2.0 AU	48	32.00
	2.1 - 5.0 AU	87	58.00
	> 5.0 AU	15	10.00

Note: The profiles indicate that the majority of respondents fall within the national working- age demographic (defined as 15-64 years by Statistics Indonesia (2020)), possessing substantial farming experience, although cattle ownership remains at a small-scale level

This uniformity was also of scientific importance, as it implied that the implementation of optimized feeding was not due to any wealth differences but to more external factors (proximity to biomass surpluses). Therefore, the results presented in Table 5 showed that the conclusions drawn regarding the comparison of different observed economic variations were mainly due to the feed management strategies.

Potential biomass and nutrition constraint

The integration of the regional agronomic data provided an overall picture of the available feed resources in total in Subang. Paddy residue was the major feed resource available in the region, representing more than 95% of the total DM, but it did not necessarily imply that it was adequate in quality. However, because of the presence of a high proportion of lignocellulose and silica, such gross quantities could not even be sufficient for basic maintenance and growth requirements unless technological interventions were used. The total value of these agricultural products and their respective carrying power are listed in Table 6.

The information in Table 6 reflected a paradox in which Operational CC (220,136 - 308,190 AU) and Theoretical CC (440,272 AU) must be differentiated. The former was the absolute biological limit, while the latter was a more realistic baseline that considers collection inefficiencies, losses due to spoilage, and other industrial applications such as mulching and fuel. For this reason, this operational surplus must not be interpreted as a sign of actual current feed security, but as an indicator of the ecological potential not yet exploited. The use of this surplus is strongly limited by labor availability and infrastructural constraints.

Distribution and variation of biomass in the zones

The feed resources mapping showed that there is a large spatial mismatch: the Northern irrigated lowlands are providing massive biomass, with more than a third of the cattle population present in the Central and Southern areas where feed is chronically deficient. This geographical imbalance generates a key logistical constraint, it is not a biological gap, it is an infrastructural incapacity to mobilize the underutilized northern surplus to the south.

This discrepancy in resource availability showed that the Northern zone provided more than 80% of the biomass in the region, but had less than 15% cattle. This share was based on the total BPDM of northern sub-districts (approx. 815,000 tons) and the regional total (1003,822 tons). Meanwhile, the Central and Southern sub-districts had approximately 86.8% of the cattle (approx. 20,400 AU), which showed a high geographical imbalance. This is a good example of how regional feed security is limited by the challenge of getting large amounts of residues from one topographical zone to another in the dry season. In addition, although upland secondary crops present better nutritional qualities, the total biomass of all secondary crops was too low to act as an ecological buffer at the macro-level against this spatial crisis, as shown in Tables 6 and 8.

Smallholder beef cattle systems' socio-economic resilience

Agricultural by-products represent an ecological buffer, which in turn translates directly to measurable socio-economic resilience. Table 9 shows the comparative analysis of the conventional and optimized feeding systems during the dry season, which shows the huge difference in financial aspects. The R/C ratio for the conventional system is 1.26, whereas that for the optimized system is 1.58, which is significantly better. The net gain of the conventional system is USD 0.10/day, while that of the optimized system is USD 0.70/day, which is significantly better.

Table 9 shows that there was a highly significant economic improvement after changing to an optimized feeding system. The Daily Profit Margin increased sevenfold from USD 0.10 to USD 0.70 per AU ($U = 346.5$, $Z = -8.14$, $p < 0.001$), confirming that the financial return of the optimized system is statistically superior to traditional grazing. This expansion was primarily driven by a statistically significant reduction in total daily input costs ($U = 512.0$, $Z = -7.31$, $p < 0.001$), as the heavy reliance on expensive commercial concentrates was successfully substituted with processed, locally available crop residues. Furthermore, the improvement in biological performance, characterized by an increase in average daily gain (ADG) from 0.45 kg to 0.55 kg, was also found to be statistically robust ($U = 1318.0$, $Z = -4.11$, $p < 0.001$), confirming that the biological buffer of agricultural by-products provided a consistent foundation for economic resilience.

Table 7. Sub-district-level distribution of feed potential vs. actual cattle population (2025)

Topographical zone	Representative sub-district	Biomass production (BPDM) (Tons/Year)	Potential CC (AU)	Actual cattle population (AU)	CCI	Feed status
Northern lowlands	Pusakanagara	152,400	66,842	850	78.64	Surplus
	Ciasem	148,200	65,000	1,050	61.90	Surplus
	Legonkulon	145,500	63,816	750	85.09	Surplus
	Pamanukan	151,300	66,360	950	69.85	Surplus
	Sukasari	151,500	66,447	900	73.83	Surplus
Central buffer	Cipunagara	85,200	37,368	2,100	17.79	Surplus
	Cibogo	12,400	5,438	3,450	1.57	Surplus
	Cikaum	45,600	20,000	1,850	10.81	Surplus
	Purwadadi	8,200	3,596	4,200	0.85	Equilibrium
	Cipeundeuy	4,500	1,973	3,800	0.51	Deficit
	Pabuaran	3,100	1,359	4,100	0.33	Deficit
	Kalijati	2,800	1,228	3,550	0.34	Deficit

Note: Potential CC is calculated as BPDM divided by the annual requirement of 2.28 tons DM/year per AU. CCI is the ratio of Potential CC to Actual Cattle Population (AU)

Table 8. Spatial disparity between biomass production and beef cattle population in Subang District, West Java, Indonesia

Topographical zone	Agronomic and ecological characteristics	Share of regional biomass production	Share of beef cattle population	Zonal feed status
Northern lowlands	Flat irrigated lowlands; intensive rice farming	> 80%	< 15%	Acute surplus
Central and Southern	Rugged upland terrain; traditional rearing hubs	< 20%	> 85%	Chronic deficit

Note: Data is obtained from BPS Subang (2025). The percentage shares are based on the regional distribution of BPDM and AU. Ecological characteristics are synthesized based on field observations as discussed under the "Spatial distribution and zonal disparities of biomass" sub-section

Table 9. Economic feasibility and R/C ratio of conventional and optimized feeding system (during dry season/per AU/day)

Economic parameters (USD/day)*	Conventional ($n = 102$)	Optimized ($n = 48$)	Test statistics [Mann-Whitney U (Z); p-value]	Data source
Input costs:				
Forage / by-product cost	0.65 + 0.08	0.24 + 0.03	$U = 512.0$ ($Z = -7.31$); $p < 0.001$	Field survey (mean)
Concentrate / supplement	0.50 + 0.06	0.43 + 0.05	$U = 1864.5$ ($Z = -2.03$); $p = 0.042$	Field survey (mean)
Labor & handling	0.30 + 0.04	0.52 + 0.06	$U = 720.5$ ($Z = -6.44$); $p < 0.001$	Table 4 (assumptions)
Total daily cost (A)	1.45 + 0.12	1.19 + 0.09	$U = 945.0$ ($Z = -5.72$); $p < 0.001$	Sum of costs
Output METRics:				
Mean ADG (kg/day)	0.45 + 0.05	0.55 + 0.04	$U = 1318.0$ ($Z = -4.11$); $p < 0.001$	Survey triangulation
Daily revenue (B)**	1.55 + 0.17	1.89 + 0.14	$U = 1318.0$ ($Z = -4.11$); $p < 0.001$	$ADG \ x \ P_{lw}$ (USD 3.44)
Profit & efficiency:				
Daily profit margin (B - A)	0.10 + 0.02	0.70 + 0.09	$U = 346.5$ ($Z = -8.14$); $p < 0.001$	Net gain
R/C ratio	1.07	1.58	-	B / A

Note: *Converted at IDR 16,000/USD. ** Daily Revenue based on standardized live-weight price P_{lw} of USD 3.44/kg. Values are presented as Mean ± Standard Deviation. Statistical significance was determined using the non-parametric Mann-Whitney U test via SPSS ($\alpha = 0.05$)

Table 10. Resource sharing and risk management measures among feeding systems

Economic parameter	Conventional system	Optimized system
Forage procurement	Distant natural grass (>5 km)	Localized crop residues
Cash flow pressure	High (market concentrate dependency)	Low (on-farm residue substitution)
Labor allocation	High-intensity transport (4 hours/day)	Technical processing (1.5 hours/day)
Economic buffer	Vulnerable to seasonal price shocks	High resilience (7x higher profit margin)

Note: Labor time estimates and resource allocation patterns are synthesized from field survey observations (*n* = 150). The baseline quantitative financial metrics (profit margins and input costs) are derived from Table 9 and further discussed in the preceding text

Based on the result of this study, there is potentially a self-selection bias in the optimized group (*n* = 48). The farmers who have introduced the residue-processing technologies might not have been different in terms of the management motivation or technical skill from the conventional group in their nature. But demographic and asset homogeneity (age, education, and herd size at baseline) between the 2 groups indicate that adoption was not necessarily a function of wealth or formal education differences, as shown in Table 5. This comparability supports the assumption that the differences in the economy that are observed are largely due to the feed management strategies used, and not to any pre-existing socio-economic differences. This bias is present in non-randomized field studies, but the sevenfold difference in profit margins indicates that the optimized feeding approach is still a strong determinant of household resilience.

Resource allocation and labor dynamics

The paradigm shift in farm-level microeconomics is explained further with a comparison of strategies for the allocation of resources and labor. The transition (as synthesized in Table 10) is a strategic change from high physical labor (distances travelled > 5 km to forage) to value-added technical work (on-farm processing of residues).

The evidence in Table 10 suggested that by decoupling productivity from local forage scarcity, the optimized system reallocated approximately 2.5 hours of daily labor from transport to processing. This shift not only improved the net profit margin (which is 7.0 times higher than the conventional system) but also enhanced the overall stability of the farming household against seasonal environmental shocks, effectively transforming agricultural waste into economic resilience.

Discussion and policy implications

The empirical results of this study provided contextual insights into the socio-ecological dynamics of livestock management in the seasonally dry tropics, which possessed distinct vulnerability characteristics compared to intensive mixed-farming systems. The spatial mapping strongly suggested that the feed deficit experienced by smallholder farmers was consistent with an allocative and logistical bottleneck, rather than an absolute lack of biological biomass. As shown in Table 7, the high CC generated by paddy residues in the northern lowlands (with CCI values ranging from 61.90 to 85.09) juxtaposed against the cattle-dense southern uplands (where CCI drops to as low as 0.33 in sub-districts like Pabuaran) was consistent with the reality of land-use competition in Java (Rachmita et al. 2021). As highlighted by local studies on spatial livestock dynamics (Agus and Widi 2018) alongside global biomass assessments (Herrero et al. 2013), fertile irrigated zones are strictly governed for staple food security, which appears to contribute to the marginalization of smallholder cattle farming in topographically challenging terrains.

This spatial separation could be the reason for the continuing vulnerability of the traditional pastoral production system in the transitional agro-climates, despite the fact that there was a feed surplus of more than 1 million tons of DM at the macro-level (Table 6). In the absence of inter-zonal feed mobility, there were potential risks of overgrazing in the central and southern pastures, and natural forage would run out quickly. This was a localized depletion in line with the global forage scarcity warnings by Godde et al. (2021). This spatial mismatch suggested a need for a good supply chain to move agricultural by-products from the surplus sub-districts in the north to the deficit sub-districts in the middle and south, where crop residue mobilization was also a key point in both national and regional contexts (Syamsu et al. 2003; Valbuena et al. 2019).

A rather distinct result was obtained when comparing our regional data with the accepted semi-arid concepts. In global literature on tropical livestock, true dryland ecosystems were often defined by being inherently unsuitable for productive use and dependent on the provision of external concentrates or pastoral expansion to maintain herd productivity (de Haan 2016). However, this model suggested a particular context-specific limit, the use of current local crop residues has substantial potential for biological sufficiency for the potential buffering effect of seasonal climatic constraints. As a result, this work suggested a review of the traditional paradigm, which is solely pro-high grains. The results suggested that a strong inter-zonal biomass mobility framework could prove to be a main force of ecological buffering. This was an empirical verification of the global feed-food competition analysis performed by Mottet et al. (2017), suggesting that ruminants must be fed mostly non-human edible biomass. In addition, this corresponds with the concepts of circular bioeconomy and integrated crop-livestock production, which are proposed internationally by Lemaire et al. (2014), Valbuena et al. (2019), and Balehegn et al. (2020).

Socio-economic resilience, the empirical results show that the use of agricultural by-products can serve as an important economic defense mechanism. In years of long dry seasons, environmental uncertainties were likely to impact the availability of natural forages and increase the price elasticity of traditional feed markets. Farmers using the conventional system seem to be exposed to such a high cost paradigm, with only a small profit margin of USD 0.10 per AU per day (Table 9), and small changes in the market could lead to loss of money, a scenario typical of the poverty trap in smallholder agriculture (Morton 2007; Tittonell and Giller 2013). Moreover, this low margin was a major empirical obstacle to the adoption. Conventional farmers without external assistance or cooperative capital were not able to invest in mechanical choppers or fermentation inputs to change to the optimized system. The noted economic resilience of the optimized system was attributed to the practical implementation of straw chopping and fermentation technologies, which could significantly increase the daily profit from a marginal value of USD 0.10 in the conventional grazing system to a more stable USD 0.70 profit. In practice, the 'optimized' practice by the sampled smallholders mainly consists of mechanical chopping of rice straw followed by urea-treatment or fermentation with indigenous probiotic starters. Biochemically and economically, these fermentation technologies could potentially enable farmers to 'unlock' trapped nutrients of the lignocellulosic biomass at a marginal cost close to 0 (Sarnklong et al. 2010; Ünlü et al. 2022).

The restructuring of the labor dynamics, as summarized in Table 10, showed a strategic paradigm shift from exertion to technical optimization. The current biomass procurement model was conventional, consisting of smallholders who invested considerable money and time in the transactions, and during the peak dry season, 72% of farmers walked more than 5 km per day to harvest wild grasses. However, the optimized system successfully uncouples farm productivity from the spatial scarcity of forage. Farmers save 18% off cash-flow pressures by replacing commercial concentrates with treated local residues, while also freeing up about 2.5 hours of their daily time, which was no longer spent collecting grass, but processing it on their farm. All these activities saved labor, which directly supported household economic resilience to seasonal environmental shocks.

This is because this mechanism of economic defense was consistent with the socio-economic evaluations of Arifah et al. (2022) and Mailena et al. (2023), indicating that feed independence was one of the factors affecting the survival of smallholders. In addition, although this study did not empirically test commercial feedlots, it did offer a comparison to other studies on intensive livestock models in context. In commercial systems, the primary focus was often the attainment of the maximum biological ADG using high-energy diets (Salami et al. 2019). In the context of smallholder seasonally dry systems, these results showed that the focus on pure biological ADG could not be economically sensible when the marginal cost of external feed was higher than the marginal value of the meat. In these sensitive systems, socio-economic resilience seems to be more important than only biological efficiency (Thornton et al. 2009). The results supported the hypothesis that agricultural by-product utilization is a basic approach of socio-economic resilience. This flexibility in the economy could enable farmers not to sell their biological assets in times of drought. Farmers also cut back on pressure on sensitive upland pasture by moving their livestock from natural forage to crop residues, thereby creating an ecological recovery window, a fundamental aspect of socio-ecological resilience. This shift preserved wider economic stability in smallholders' income generation (Widiati and Widi 2016). But these positive short-term socio-economic measures hint at high adaptive capacity, and these long-term resilience claims must be read with some skepticism. This study did not represent multi-year longitudinal monitoring but rather a snapshot of economic stability in the field based on the cross-sectional data, and some changes in economic stability were likely to arise as macro-economic pressures change or as there are severe multi-year climatic anomalies.

The direct evidence provided in this study, a spatial mismatch of biomass and an enormous margin improvement of USD 0.70 per day, compared to USD 0.10 per day, showed that it could be worthwhile for agricultural ministries to prioritize investments in biomass logistical infrastructures and on-farm processing capacities from a policy perspective. The data clearly shows the allocative gap between surplus and deficit regions, both north and south, and policy could look at physically connecting the north and south rather than just subsidizing the commercial feed. Although the empirical results overwhelmingly indicate the need for these logistical and processing interventions, the data cannot answer the question of what institutional mechanisms are necessary to actually implement these interventions. Hence, further feasibility studies are necessary to assess potential avenues (e.g., farmer cooperatives to share transport resources or agricultural extension services to be targeted to reduce technical constraints of manual processing) as they should not be treated as policy prescriptions at this moment. This is a prudent, context-specific institutional strategy, and in line with the international literature, which has shown that adaptation strategies for smallholder farmers are best implemented through context-specific extension delivery systems tailored to the socio-economic profiles of these resource-limited farmers (Antwi-Agyei and Stringer 2021).

Some limitations were observed, despite its solid methodological performance. In this study, there were drawbacks to using general literature-based conversion factors for localized CC estimates. Actual crop residue yields and DM percentages varied with micro-climatic moisture conditions at harvest, soil fertility, and variation of harvesting practices (mechanical combine harvesters versus sickle harvesting). These generalized coefficients were used as a baseline for regional macro-level planning and policy development, but did not necessarily reflect the fine-scale temporal and spatial variation of biomass availability at the individual farm level. In terms of representativeness, a distinction must be made between the 2 scales of this study, spatial and socio-economic. In the macro-level CC mapping (Tables 6 and 7), secondary data obtained from the region are representative of Subang District as a whole, while in the economic metrics (Table 9) and resource allocation observation (Table 10), the obtained data are only representative of the 7 surveyed sub-districts in the central zone and south zone of Subang District. First, the use of secondary data for regions suggested that the DM conversion and physiological requirements of cattle in each region are assumed to be the same, which could not be the case when the local climatic stresses were different. Second, the economic assessment (Table 9) is based on a deterministic model of direct operational costs, not explicitly accounting for equipment depreciation or nuanced inter-zonal transport tariffs, and so the precise generalizability of the profit margins is restricted. Third, since the spatial modelling used was at the macro-level and the focus of this study was on the spatial modelling, the economic assessment (Table 9) is based on a representative field sample and localized price assumptions and has not been sampled exhaustively in a socio-economic sense. This restriction naturally restricts the wide applicability of the actual profit margins given. Last, there can be some frictions that are not adequately picked up in the spatial mapping at the sub-district level. Future research should focus on conducting comprehensive primary socio-economic surveys and finer level mapping of logistics costs to identify specific logistics costs for by-product mobilization in different provinces. Finally, in this study, the idea of combining spatial agricultural by-product mapping with the socio-economic adaptability of smallholders was not only set in a local context as a coping strategy, but also as a framework for sustaining seasonally dry tropical livestock systems in the long-term.

In conclusion, this study shows that the reason for the perennial feed problem in Subang District is due to the inefficiency in the distribution of feed resources and not due to biological shortage of resources in the seasonally dry tropics. The northern regions have a very large untapped biomass surplus, while the southern regions are where livestock are concentrated and could be at risk. This is due to their being geographically isolated from the resources and because traditional forage procurement is very labor-intensive. These results validate that switching to an optimized feeding system (mechanical chopping and fermentation of local crop residues) substantially contributes to farm-level socio-economic resilience, widened profit margins, and less reliance on costly commercial inputs. However, it is recognized that the actual cost modeling for transportation at the micro-level has not been performed yet, and future study needs to include the economic evaluation at the micro-level to fully operationalize the proposed inter-zonal biomass mobility. Finally, it is recommended to shift the policy from traditional feed subsidy to strategic investments in biomass mobilization and on-farm processing infrastructure in this region. Combining spatial resource mapping and socio-economic adaptability offers a framework that can be scaled up to ensure sustainable smallholder livestock systems in forage-limited settings.

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REFERENCES

Agus A, Widi TSM. 2018. Current situation and future prospects of beef cattle production in Indonesia - A review. Asian-Australas J Anim Sci 31 (7): 976-983. https://doi.org/10.5713/ajas.18.0233.

Antwi-Agyei P, Stringer LC. 2021. Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from Northeastern Ghana. Clim Risk Manag 32: 100304. https://doi.org/10.1016/j.crm.2021.100304.

Arifah, Salman D, Yassi A, Demmallino EB. 2022. Livelihood vulnerability of smallholder farmers to climate change: A comparative analysis based on irrigation access in South Sulawesi, Indonesia. Reg Sustain 3: 244-253. https://doi.org/10.1016/j.regsus.2022.10.002.

Badan Perencanaan Pembangunan Daerah (Bappeda) Subang. 2021. Regional spatial plan (RTRW) of Subang District. Regional Development Planning Agency of Subang District, Subang, Indonesia. [Indonesian]

Badan Perencanaan Pembangunan Daerah (Bappeda) Subang. 2025. Regional leading commodity mapping report. Regional Development Planning Agency of Subang District, Subang, Indonesia. [Indonesian]

Badan Pusat Statistik (BPS) Subang. 2025. Subang District in Figures 2021-2025. BPS-Statistics of Subang District, Subang, West Java, Indonesia. [Indonesian]

Balehegn M, Duncan A, Tolera A, Ayantunde AA, Issa S, Karimou M, Zampaligré N, André K, Gnanda I, Varijakshapanicker P, Kebreab E. 2020. Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low-and middle-income countries. Glob Food Secur 26: 100372. https://doi.org/10.1016/j.gfs.2020.100372.

Budisatria IGS, Udo HMJ, Eilers CHAM, Baliarti E, Van der Zijpp AJ. 2010. Preferences for sheep or goats in Indonesia. Small Rumin Res 88 (1): 16-22. https://doi.org/10.1016/j.smallrumres.2009.11.002.

Cortner O, Garrett RD, Valentim JF, Ferreira J, Niles MT, Reis J, Gil J. 2019. Perceptions of integrated crop-livestock systems for sustainable intensification in the Brazilian Amazon. Land Use Policy 82: 841-853. https://doi.org/10.1016/j.landusepol.2019.01.006.

de Haan C. 2016. Prospects for Livestock-Based Livelihoods in Africa's Drylands. World Bank, Washington DC. https://dx.doi.org/10.1596/978-1-4648-0836-4.

Directorate General of Livestock and Animal Health Services. 2020. Animal Unit Conversion Guidelines. Ministry of Agriculture of the Republic of Indonesia, Jakarta, Indonesia. [Indonesian]

Dumont B, Ryschawy J, Duru M, Benoit M, Chatellier V, Delaby L, Donnars C, Dupraz P, Lemauviel-Lavenant S, Méda B, Vollet D, Sabatier R. 2019. Review: Associations among goods, impacts and ecosystem services provided by livestock farming. Animal 13 (8): 1773-1784. https://doi.org/10.1017/S1751731118002586.

Geospatial Information Agency. 2025. Topographic Map of Indonesia (Peta Rupa Bumi Indonesia): Subang District Series. Badan Informasi Geospasial, Cibinong, Indonesia. [Indonesian].

Godde CM, Mason-D'Croz D, Mayberry DE, Thornton PK, Herrero M. 2021. Impacts of climate change on the livestock food supply chain; A review of the evidence. Glob Food Sec 28: 100488. https://doi.org/10.1016/j.gfs.2020.100488.

Herrero M, Havlík P, Valin H, Notenbaert A, Rufino MC, Thornton PK, Blümmel M, Weiss F, Grace D, Obersteiner M. 2013. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. Proc Natl Acad Sci USA 110 (52): 20888-20893. https://doi.org/10.1073/pnas.1308149110.

Lemaire G, Franzluebbers A, de Carvalho PC, Dedieu B. 2014. Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. Agric Ecosyst Environ 190: 4-8. https://doi.org/10.1016/j.agee.2013.08.009.

Mailena L, Saptati RA, Ermuna SS, Rohaeni ES. 2023. Potency and strategy for developing beef cattle business in South Kalimantan. The 3rd International Conference on Environmentally Sustainable Animal Industry 2022 (ICESAI 2022) (pp. 100-112). Atlantis Press, Malang. https://doi.org/10.2991/978-94-6463-116-6_14.

Makkar HPS. 2016. Smart livestock feeding strategies for harvesting multiple benefits from mixed crop-livestock systems in developing countries. Anim Prod Sci 56 (3): 519-534. https://doi.org/10.1071/AN15557.

Morton JF. 2007. The Impact of Climate Change on Smallholder and Subsistence Agriculture. Proc Natl Acad Sci USA 104 (50): 19680-19685. https://doi.org/10.1073/pnas.0701855104.

Mottet A, de Haan C, Falcucci A, Tempio G, Opio C, Gerber P. 2017. Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. Glob Food Secur 14: 1-8. https://doi.org/10.1016/j.gfs.2017.01.001.

Oldeman LR, Las I, Muladi. 1980. The Agroclimatic Maps of Kalimantan, Maluku, Irian Jaya and Bali, West and East Nusa Tenggara. Contribution Central Research Institute for Agriculture, Bogor.

Oldeman LR. 1975. An Agro-Climatic Map of Java. Contribution. Central Research Institute for Agriculture, Bogor.

Rachmita N, Wibowo A, Koestoer RH. 2021. Spatial patterns of expertise suitability in the ruminant sub-sector of Subang Regency, West Java Province. IOP Conf Ser Earth Environ Sci 940: 012011. https://doi.org/10.1088/1755-1315/940/1/012011.

Salami SA, Luciano G, O'Grady MN, Biondi L, Newbold CJ, Kerry JP, Priolo A. 2019. Sustainability of feeding plant by-products: A review of the implications for ruminant meat production. Anim Feed Sci Technol 251: 37-55. https://doi.org/10.1016/j.anifeedsci.2019.02.006.

Sarnklong C, Cone JW, Pellikaan W, Hendriks WH. 2010. Utilization of rice straw and different treatments to improve its feed value for ruminants: A review. Asian-Australas J Anim Sci 23 (5): 680-692. https://doi.org/10.5713/ajas.2010.80619.

Statistics Indonesia. 2020. Statistical Yearbook of Indonesia 2020. Badan Pusat Statistik, Jakarta, Indonesia. [Indonesian]

Subang Agriculture Agency. 2024. Livestock Production Cost Standards of Subang District 2024. Agriculture Agency of Subang District, Subang, Indonesia. [Indonesian]

Subang Livestock Agency. 2025. Ruminant Population Report of Subang District. Livestock and Animal Health Agency of Subang District, Subang, Indonesia. [Indonesian]

Syamsu JA, Sofyan LA, Mudikdjo K, Said EG. 2003. Daya Dukung Limbah Pertanian sebagai Sumber Pakan Ternak Ruminansia di Indonesia. Puslitbang Peternakan. Badan Litbang Pertanian. Deptan 13 (1): 1-10. [Indonesian]

Thornton P, Herrero M, Freeman A, Mwai O, Rege E, Jones P, McDermott J. 2009. Vulnerability, climate change and livestock-opportunities and challenges for the poor. J Semi-Arid Tropic Agric Res 4 (1): 1-10.

Tittonell P, Giller KE. 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. Field Crop Res 143: 76-90. https://doi.org/10.1016/j.fcr.2012.10.007.

Ünlü HB, Kirkpinar F, Ozdogan M. 2022. Nutritional evaluation of the agro-industrial by-products and waste fruits - vegetable for sustainable ruminant nutrition. J Hell Vet Med Soc 73 (1): 3657-3666. https://doi.org/10.12681/jhvms.25386.

Valbuena D, Erenstein O, Homann-Kee Tui S, Abdoulaye T, Claessens L, Duncan AJ, Gérard B, Rufino MC, Teufel N, van Rooyen A, van Wijk MT. 2019. Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. Field Crop Res 132: 175-184. https://doi.org/10.1016/j.fcr.2012.02.022.

Wanapat M. 2009. Potential uses of local feed resources for ruminants. Trop Anim Health Prod 41 (7): 1035-1049. https://doi.org/10.1007/s11250-008-9270-y.

Widiati R, Widi TSM. 2016. Production systems and income generation from the smallholder beef cattle farming in Yogyakarta Province, Indonesia. Anim Prod 18 (1): 51-58. https://dx.doi.org/10.20884/1.jap.2016.18.1.524.