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System Dynamics Modeling of Sustainability, Animal Welfare, and Certification in the Luwak Coffee Industry

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Abstract

Luwak coffee, globally recognized yet ethically contested, represents one of Indonesia's most distinctive and high-value commodities. Despite its reputation, production remains small-scale and constrained by sustainability challenges, animal welfare concerns, and supply chain inefficiencies. This study aims to analyze the structure and behavior of the civet coffee production system using a system dynamics approach. Causal loop diagrams and stock–flow models were constructed to simulate policy scenarios across population dynamics, animal health, coffee cherry availability, certification, and market reputation. The results indicate that civet population growth is positively influenced by improved health and reduced mortality, while stress levels decline under enhanced welfare practices. Certification and reputation emerge as reinforcing drivers of market acceptance but remain highly vulnerable to negative publicity regarding animal welfare. Scenario analysis demonstrates that sustainable habitat management, investment in certification, and ethical compliance not only strengthen green bean stocks but also enhance long-term production resilience. Conversely, stagnant sales trends highlight that production capacity alone is insufficient without consumer trust and reputational legitimacy. These findings imply that integrating welfare-based management, ecological sustainability, and certification-driven reputation building is essential to ensure the long-term viability and competitiveness of the civet coffee industry.

INTRODUCTION

Civet coffee, or kopi luwak, is one of the most distinctive coffee varieties originating from Indonesia, long recognized as an exotic product in the international market. Its unique fermentation process, which occurs naturally in the digestive tract of civets (Paradoxurus hermaphroditus), produces an uncommon flavor profile that is often considered exceptional by premium coffee connoisseurs. Typically processed from Arabica and Robusta beans, civet coffee differs from regular coffee in its harvesting method: while ordinary beans are picked directly from trees, civet coffee is collected from civet droppings (Lukman, 2022). Similar trends exist globally, such as Thailand's "Black Ivory

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Coffee" produced from elephant digestion, a product also linked to conservation initiatives, and the Jacu bird coffee in South America. In West Java, notable production areas include Lembang, Bandung Regency, Sumedang, Garut, Priangan, and Pangalengan. Despite its significant potential, civet coffee production in this province remains small-scale and poorly documented in official statistics, making it difficult to evaluate its real contribution to the regional coffee industry.

According to data from the West Java Provincial Plantation Agency, Arabica coffee production in Bandung and Garut reached 5,277 and 1,970 tons respectively in 2017. In contrast, civet coffee volumes are substantially lower. For instance, the Gapoktan Kopi Paniis cooperative in Sumedang, recognized as a local civet coffee producer, managed to produce only 2.5 tons of civet coffee from an annual harvest of 15 tons of coffee beans. This contrast highlights that although civet coffee holds high market value, its scale of production is still limited and has yet to become a central focus in the region's coffee agribusiness sector.

Sustainability and ethical concerns also play a crucial role in shaping consumer preferences for civet coffee. The Indonesian government has issued specific regulations on civet coffee production, such as Ministry of Agriculture Regulation No. 37 of 2015 and Ministry of Environment and Forestry Regulation No. 18 of 2024. The main focus is animal welfare, particularly in farmed civets' housing and care practices. Reports suggest that poor husbandry, cramped cages, and inappropriate facilities compromise civet well-being, potentially undermining the product's international reputation (Acta Veterinaria Indonesiana, 2021). Welfare standards are assessed across dimensions such as freedom from hunger, stress, discomfort, and the ability to engage in natural behaviors. Studies show that conditions in captivity are slightly better than in the wild, due to regular feeding and cleaner enclosures. However, welfare in animal markets is significantly worse, with civets often kept in noisy, crowded, and sun-exposed cages; only 15% have access to water, and mobility is severely restricted (Lewis-Whelan et al., 2024). These conditions indicate that current practices, even in captivity, still fall short of national welfare regulations.

Beyond ethical concerns, challenges within the civet coffee supply chain persist. Farmers frequently highlight the unequal distribution of value: while they are the backbone of production, they receive the smallest share of profits. Limited access to transparent market information, certification, and technology further exacerbate inefficiencies. Export barriers also remain: as noted by (Ginanjar et al., 2020), local producers face bureaucratic hurdles in obtaining export permits. Moreover, production volumes are insufficient to meet export demand. Ariffien & Made Wicaksana, (2021), for example, reported that Kopi Luwak Cikole, with an output of 200 kg per month, consistently fails to meet market expectations.

Several previous studies have examined aspects of civet coffee. Suharyanto et al., (2020) analyzed distribution channels in West Java, Yuliani and Rachmawati (2019) emphasized digitalization to strengthen value chains, while Noviantari et al., (2015) explored supply chain structures and value addition. However, these studies remain partial, lacking a comprehensive perspective that links supply chain dynamics with long-term sustainability. Considering the coffee supply chain involves multiple interrelated factors, including consumer behavior, animal welfare, price volatility, and regulatory frameworks, such a systemic approach is crucial.

In response, this study seeks to develop a deeper understanding of the

structure and dynamics of the civet coffee supply chain in West Java. Using a system dynamics approach, the research aims to construct a model that captures the interactions among supply chain actors and external factors such as government policies, market fluctuations, and farming practices. The model will also simulate alternative policy scenarios to assess their potential impacts on efficiency, productivity, and sustainability. Ultimately, the findings are expected to provide actionable recommendations for stakeholders, including farmers, cooperatives, and policymakers, to ensure civet coffee production remains socially responsible, economically viable, and environmentally sustainable.

METHODS

This study employed a mixed methodological approach by combining qualitative inquiry with system dynamics modeling and simulation. The qualitative component adopted a descriptive method, deemed appropriate for exploring phenomena in depth and obtaining a comprehensive understanding of the research context (Az-Zahra et al., 2025; Busral et al., 2025; Creswell, 2014; Engkizar et al., 2022, 2025; Kassymova et al., 2025; Knapp, 2003; Rahman et al., 2025). Data were collected through in-depth interviews with key respondents selected via purposive sampling, following qualitative interviewing principles that emphasize richness and depth of information (Qu & Dumay, 2011). The data analysis process followed the interactive model, consisting of data reduction, data display, and conclusion drawing (Engkizar et al., 2024; Miles & Saldaña, 2015). Insights from the qualitative findings were subsequently used to inform the design and structure of the system dynamics model.

System dynamics was chosen as the primary modeling approach due to its ability to capture interactions among variables, feedback mechanisms, and the overall complexity of the civet coffee supply chain. It allows the simulation of system behavior over time and the evaluation of alternative decision scenarios, thereby providing insights into potential impacts of different policy interventions (Ariffien & Made Wicaksana, 2021; Bayer, 2004). The model was developed using causal loop diagrams and stock–flow diagrams to represent causal relationships across upstream, production, distribution, and marketing activities.

The research applied a systems perspective by viewing the supply chain as an integrated whole that links actors, material flows, financial flows, and information networks. A quantitative approach was also employed in parameter estimation and model validation, using numerical data such as production, prices, and demand to ensure the model reflects real-world conditions and can support the formulation of effective policy strategies for sustainable civet coffee development in West Java.

The study focused on civet coffee producers in Pangalengan, Lembang, and Cianjur, purposively selected as the main production centers in West Java. Each region presents distinct characteristics: Pangalengan integrates large plantations with agro-tourism, Lembang is dominated by smallholder farmers targeting niche specialty markets, while Cianjur combines traditional farming systems with emerging commercial production. By including producers from these three regions, the study captures the diversity of production systems and provides a more comprehensive representation of civet coffee development and sustainability in West Java. The methodological sequence was structured into several steps, as illustrated in figure 1.

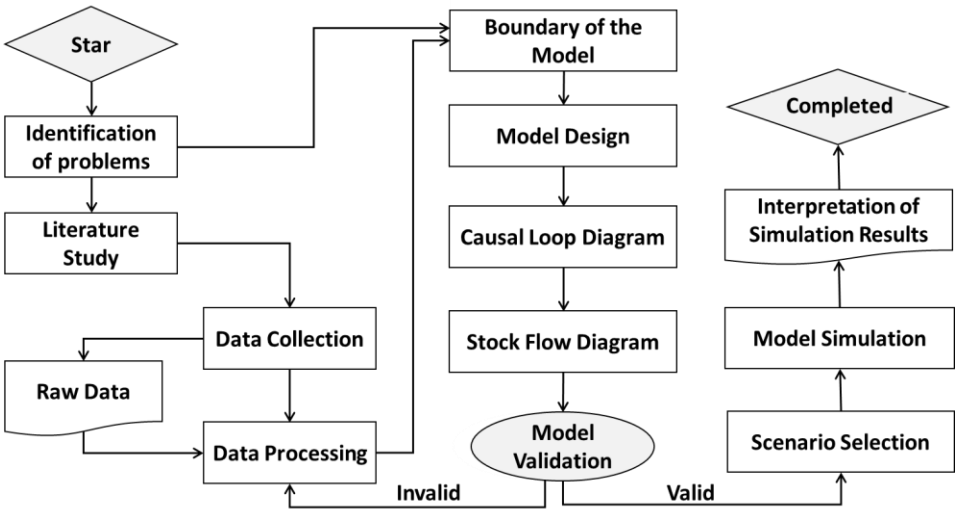

Fig 1. Research methodology diagram

Figure 1 illustrates the overall research methodology applied in this study, presented as a systematic flow from problem identification to model completion. The process begins with defining the research focus and reviewing relevant literature, followed by data collection and processing, distinguishing between raw and processed data. The model is then designed within clearly defined boundaries, represented through causal loop and stock–flow diagrams, and undergoes validation to ensure accuracy. Depending on validation outcomes, the model may be revised or advanced to scenario selection, simulation, and interpretation of results, ultimately leading to the completion of the research cycle. This structured approach ensures clarity, reproducibility, and rigor in the research methodology.

RESULT AND DISCUSSION

This section presents the results and discussion of the study, focusing on the dynamic interactions within the civet coffee (kopi luwak) production system in West Java. The findings are organized into two parts: (i) simulation outcomes illustrating production, certification, and financial trajectories under different policy scenarios, and (ii) structural analysis of feedback mechanisms to explain the drivers of long-term sustainability.

The initial simulations indicate that external factors such as climate variability and certification capacity strongly affect coffee cherry availability and, consequently, civet coffee supply. On the demand side, consumer trust and product reputation emerge as critical determinants of acceptance and pricing. Conversely, negative publicity or scandals related to animal welfare present major risks to industry sustainability, as they undermine reputation and reduce demand.

To capture these dynamics, a Causal Loop Diagram (CLD) was developed (Figure 2). The CLD illustrates interdependencies among key variables, including reputation, certification, investment, civet health, and mortality, along with reinforcing (R1) and balancing (B1, B2) feedback loops. This structural representation not only underpins the interpretation of simulation results but also highlights leverage points where policy interventions can exert the greatest influence on the long-term viability of the civet coffee industry.

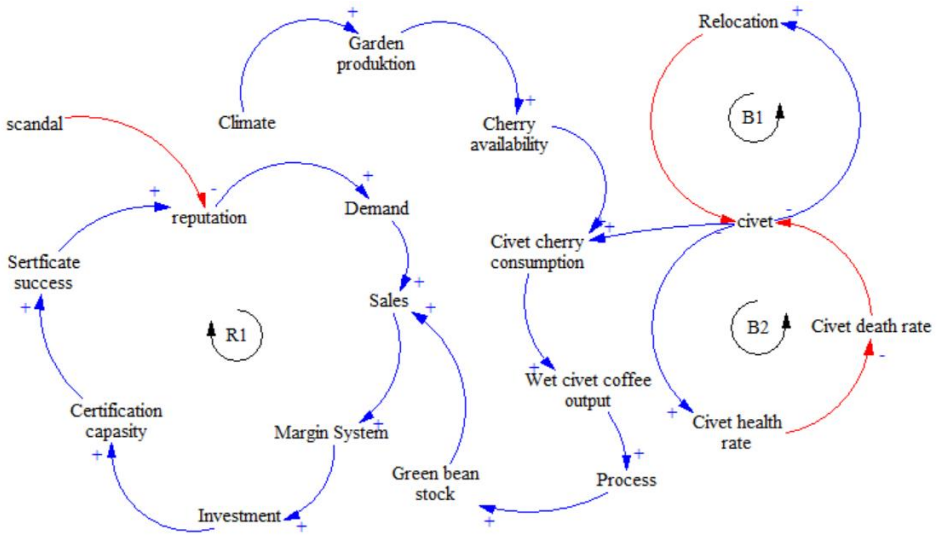

Fig 2. Causal loop diagram civet coffee

Loop R1 (Reinforcing)

Loop R1 illustrates a reinforcing cycle in which certification capacity is central. Increased investment enhances certification capacity, thereby raising the likelihood of successful certification. This mechanism aligns with evidence that certification schemes improve farmers' market access by securing higher and more stable prices, while also promoting environmental protection and human rights, enabling smallholders to capture greater value within the supply chain (Jones et al., 2024). Nevertheless, the loop remains highly vulnerable to external shocks, such as scandals, that can rapidly erode reputation and disrupt the reinforcing cycle.

Loop B1 (Civet Population and Welfare Management)

Loop B1 reflects the balancing mechanism associated with civet population management. As civet numbers rise, relocation and welfare considerations become necessary to maintain ecological balance. However, such interventions must be approached with caution: sustainable practices require alignment with ecological, social, and ethical dimensions, as symbolic measures (e.g., green marketing) are insufficient without structural improvements (Irjayanti et al., 2025). In the context of civet coffee tourism, welfare concerns are particularly evident; tourists observing caged civets often react negatively, highlighting issues of dignity, suffering, and ethical conflict (Hooper, 2022). This loop thus underscores the importance of humane, ethically grounded, and structurally supportive practices in sustaining both ecological balance and animal welfare.

Loop B2 (Balancing)

Loop B2 captures the link between civet health and mortality. Larger populations often strain captive conditions, increasing risks of disease, injury, poor nutrition, and stress-related disorders. These factors critically undermine survival, as many captive civets die from malnutrition or caffeine toxicity (Hooper, 2023). Rising mortality subsequently reduces the population, providing a natural balancing mechanism. The loop therefore reflects the biological limits of intensive civet coffee production while underscoring the need for welfare-based health management, not only as an ethical imperative but also as a prerequisite for long-term production stability.

Stock and Flow Diagram

To better understand the structural complexity of the civet coffee production system, a Stock and Flow Diagram (SFD) was developed. The SFD provides a visual representation of the system's core components, including

civet population dynamics, coffee cherry availability, certification processes, reputation, and financial feedback mechanisms. By translating qualitative insights into a formalized structure, the diagram facilitates the identification of reinforcing and balancing feedback loops that govern system behavior over time. This visual framework serves as the basis for subsequent simulation experiments, allowing for a more systematic exploration of how different policy interventions may influence long-term sustainability. Figure 3 and figure 4 presents the SFD developed in this study.

Stock–flow diagram of civet coffee production (figure 3) describes the dynamic interrelations between stocks of population, resource constraint, and management inputs of the system. Luwak population, available coffee beans, and ecosystem carrying capacity are three stocks found in this system. Each is regulated by inflows and outflows that determine system behavior in the long run. The luwak population stock accumulates naturally by birth rate and carrying capacity, while decreasing due to mortality, hunting pressure, and habitat deterioration. The model provides for a feedback effect where higher population density increases the competition for resources with a consequent reduction in survival.

Coffee bean stock is related to plantation production and consumption of luwak. Civets consume ripe coffee cherries, which subsequently pass through their digestive system to be picked for processing. The inflow of coffee cherries into the system depends on farm output, allocation of land, and time of year, and the outflow represents luwak consumption and post-harvest loss. This interaction forms a balancing feedback loop: increased coffee supply maintains higher civet populations, while over-consumption exhausts stock and potentially reduces production sustainability.

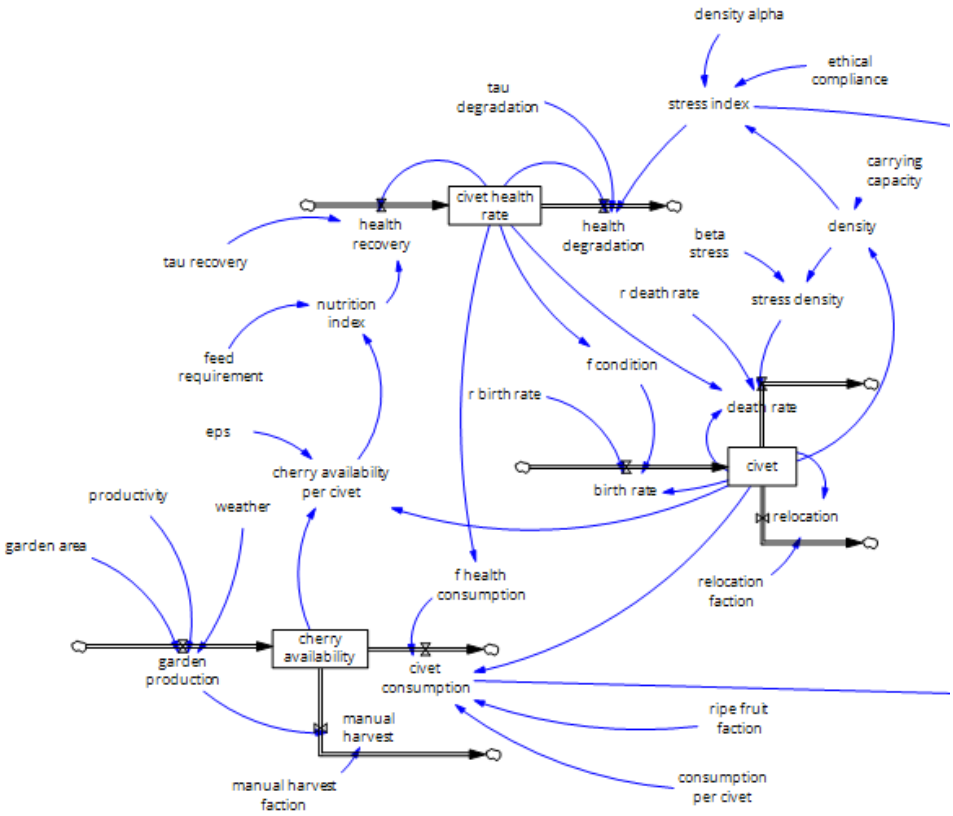

Fig 3. Civet coffee production stock flow diagram

The inventory of ecosystem capacity indicates quality habitat that is eroded by overuse, deforestation, and thin ecological restoration. In contrast,

reforestation and conservation enhance the carrying capacity such that the population of luwak can be maintained at sustainable levels. The stock highlights the expense of forgoing long-term ecosystem resilience for short-term economic gains of increased civet coffee production.

Overall, the stock–flow dynamics illustrate system stability relies heavily on balanced interaction between luwak population dynamics, coffee production capacity, and habitat sustainability. Overexploitation in the absence of conservation feedback reduces both luwak viability as well as economic returns. The model thus highlights the requirement for integrated management strategies such as habitat conservation, controlled population management, and sustainable agricultural practices for making civet coffee production economically viable and ecologically sound.

The second stock-flow diagram (figure 4) targets the sales dynamics of civet coffee and spotlights the interaction of production capacity, certification, demand variability, and price mechanism. The central stock is revenue, which accumulates from the flow of sales and depletes by operating expenses and market shocks. The stock is subject to strong impact by both endogenous factors (production capacity, certification standard, and availability of supply) and exogenous factors (demand variability, premium price expectation, and consumer concern for animal welfare).

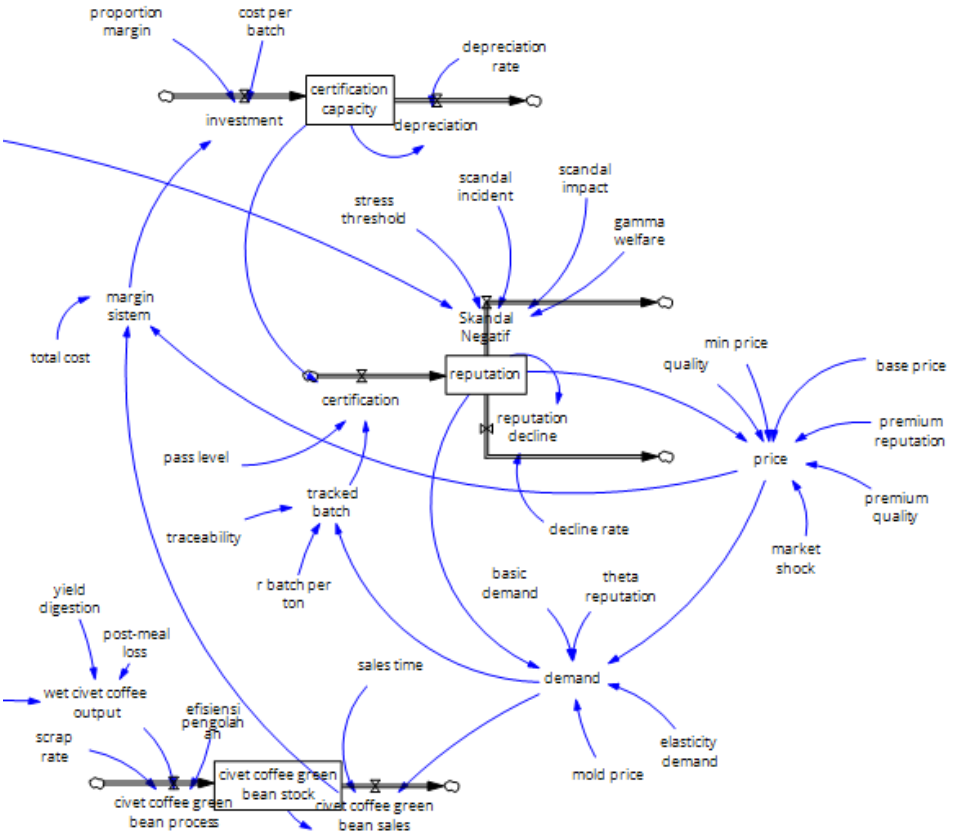

Fig 4. Civet coffee sales stock flow diagram

The certification stock also is a key reputational driver. Investment in certification enhances product legitimacy, mitigates reputational risk, and anchors premium market access. Depreciation of certification value arises as a result of lax enforcement or a decline in consumer trust, where it creates a balancing loop that affects long-term revenue stability. This demonstrates how certification is not only a compliance tool but rather a strategic asset within specialty coffee markets.

Price stock is impacted by the interactions of premium and minimum price expectations. Negative and positive shocks to market demand directly

affect price variation, and these have a subsequent effect on total revenue. As demand increases for ethically produced civet coffee, premium margins increase and revenue increases significantly. Conversely, market doubt regarding animal welfare lowers willingness to pay, resulting in price reductions and undermining sustainability of the supply chain. Of particular interest, this sales-oriented diagram is directly interfaced with the biologic and ecological model described above. Capacity of the stock of luwak population and ecosystem capacity directly constrains the supply of coffee beans that can be made. If overuse reduces civet well-being or ecosystem strength, raw material supply into the sales system is affected, decreasing certification credibility and revenue stability. Conversely, maintaining a balanced civet population and habitat supports continuous production, strengthens certification claims of sustainability, and stabilizes market prices.

Together, the two figures illustrate the double dependence of civet coffee systems: i) ecological sustainability safeguarding raw material flows, and ii) market legitimacy upholding long-term profitability. Without ecological balance, certification and premium prices are uncredible; without market trust, ecological measures fail to become earnings. This dualism highlights the necessity of system management practices that address both biological and economic conditions of civet coffee production.

The results of the developed base model are illustrated in figure 5, figure 7, figure 9 and figure 11. These graphs represent the behavior of the constructed dynamic system, providing insights into the interrelationships among variables, the temporal patterns of change, and the influence of key parameters on the overall system dynamics.

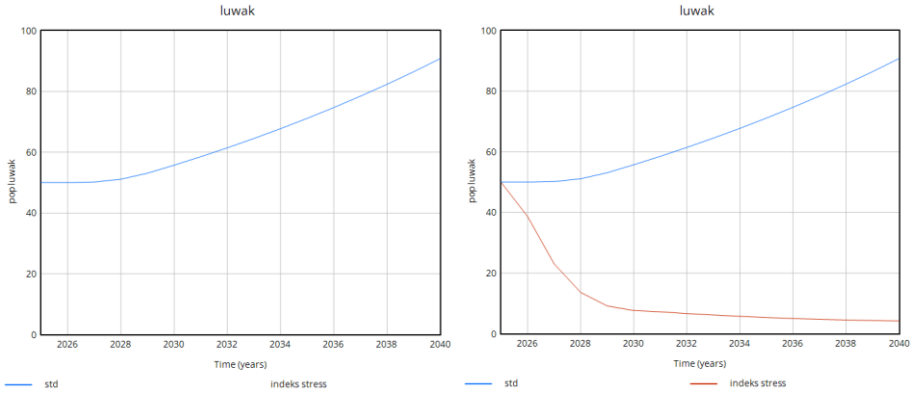

Fig 5 & 6. Civet Population Simulation & Civet Population After Scenario

As per figure 5, simulation output indicates that the growth in the number of civets from 50 to around 90 by 2040 is due to three most contributing variables: birth rate, health of civets, and population density. Improved health conditions result in low mortality levels, and a mean birth rate achieves normal recruitment of new individuals to the population. Concurrently, the ideal population density avoids overcrowding, and hence would otherwise negatively affect welfare and reproduction performance. The interaction of these variables provides a continuous rising curve for population, which is the solid foundation for sustained civet coffee production in the long run.

The outcomes presented in figure 6 are the population growth vs. stress levels interaction across different scenarios. The stress index declines sharply around 93% from 50 civet in the initial years and reaches a plateau of approximately 3 civet towards the end of the simulation. This counterintuitive trend indicates that improved welfare protocols e.g., improved shelters and reduced confinement, encourage population growth without increasing stress.

At the production stage, lower stress is strongly linked with better civet health, which in turn ensures more consistent and potentially higher yields of civet coffee. This relationship is consistent with previous studies demonstrating that chronic stress undermines key vital rates, including reproduction and survival, ultimately contributing to population decline (Nacci et al., 2001).

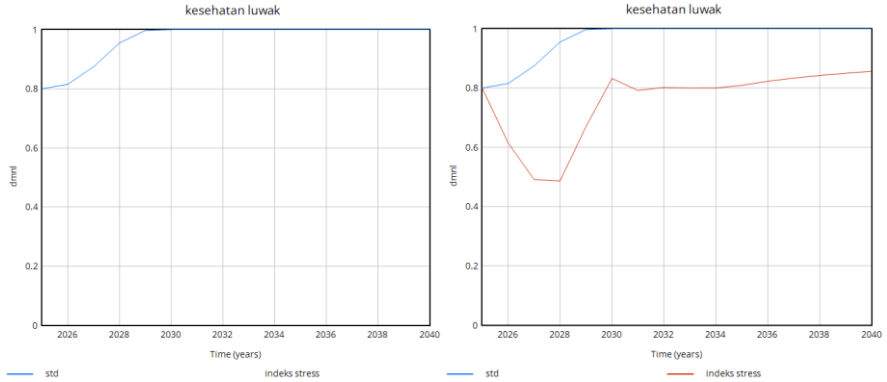

Fig 7 & 8. Civet Health Level Simulation & Civet Health Level After Scenario

As can be seen in figure 7, the health index of civets rises from 0.8 to a constant 1.0 in 2029, signifying that welfare practices on a routine basis maintain great levels of civet health without decline. This enhanced health enhances sustainable productivity in civet coffee production since healthier animals yield better beans in the long term. This outcome aligns with recent findings indicating that adherence to animal welfare standards, covering diet, hygiene, mobility, and body condition, substantially enhances operational performance and public perception of civet coffee (Lewis-Whelan et al., 2024).

This finding is also supported by the scenario analysis in figure 8, in which despite the stress index temporarily falling to 0.48 between 2026 and 2027, it gradually returns to 0.85 by 2040. Despite this trough, the overall civet health index is nevertheless at its peak after 2029, suggesting the resilience of health outcomes under extended welfare conditions. Notably, the transient decline in civet health is attributable to declining ethical compliance to 0.3, reducing the habitat carrying capacity to below 100, and lowering feed availability to 0.10. These interacting factors indicate the necessity to maintain ethical standards, decent quality habitat conditions, and feed supply stability for realizing optimum civet well-being. This means that proper management of civet welfare not only avoids stress-related risks but also ensures stable productivity in the civet coffee supply chain. These results align with recent studies emphasizing that animal welfare standards, covering nutrition, habitat quality, and ethical compliance directly improve both the quality and sustainability of specialty coffee production (Irjayanti et al., 2025; Lewis-Whelan et al., 2024).

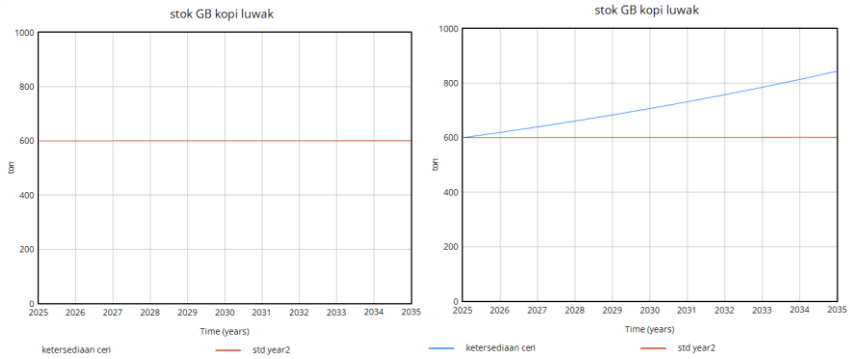

Fig 9 & 10. Green Bean Stock Simulation & Green Bean Stock After Scenario

Figure 9 demonstrates that the stock of civet coffee green beans remains at around 600 tons during the period from 2025 to 2035. This is because there is a balance of production where the input of coffee cherries, civet utilization, and processing efficacy equalize the loss resulting from the scrap rate. The implication is that as feed supply, civet health, and post-harvest management remain constant, the system will have a consistent output. This balance supports both production stability and sustainability in the long term of civet coffee.

Simulation in figure 10 results indicate that a rise in cherry supply by 15%, combined with improved processing efficiency (0.78) and lower scrap rate (0.1), leads to a dramatic rise in civet coffee green bean stock, from around 600 tons in 2025 to over 800 tons by 2035. This trend illustrates the significance of technical aspects and environmental sustainability in supporting long-term production. These findings are consistent with (Campera et al., 2021), who emphasize that wildlife-friendly farming practices, such as agroforestry and habitat enrichment, not only enhance coffee cherry availability but also contribute to biodiversity conservation. Thus, the observed increase in green bean stock can be interpreted as a synergistic outcome of improved processing practices and sustainable habitat management.

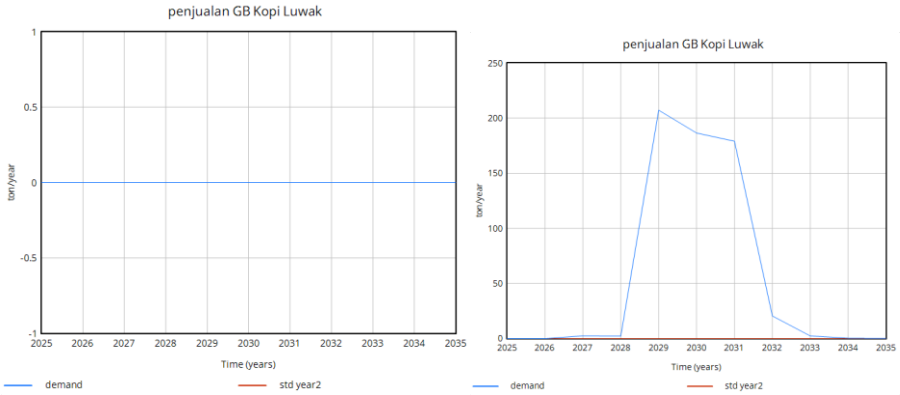

Fig 11 & 12. Civet Coffee GB Sales Simulation & Civet Coffee GB Sales After Scenario

Figure 11 shows the sales of Civet Coffee Green Beans remain consistently close to zero tons annually across the 2025–2035 duration with no discernible upwards or downwards trend. This reflects that although inventories of green beans are present, absorption in the market is zero, reflecting level demand over the observed duration.

Figure 12 demonstrates how, unlike the plateaued trend presented by Figure 11, Civet Coffee Green Beans sales increase rapidly from 2028. This steep increase coincides with increased investment to 100 batches and the enhancement of reputation, which heightened consumer trust in the authenticity and quality of the product. Sales peaked in 2029 at approximately 210 tons/year, then declined gradually until 2031, before steeply plummeting after 2032 and falling to near-zero levels once more by 2034. Compared to the earlier result (figure 11), where demand was level even when adequate stock was available, this result highlights the key role of investment and reputation in driving absorption within the market. Specifically, sufficient investment provides for the capacity to increase output and distribution capacity, while improved reputation translates into greater consumer acceptability, hence closing the plateau of demand mentioned above.

These findings are consistent with international evidence. A large-scale meta-analysis confirms that ecolabels, particularly Organic, Fair Trade, and

origin-based certification, consistently increase consumer price acceptance across different markets (Abdu & Mutuku, 2021). Similarly, studies on voluntary sustainability standards such as Fair Trade and UTZ demonstrate that certifications can significantly enhance market value when consumer awareness is sufficiently strong (Merbah & Benito-Hernández, 2024). Collectively, these insights reinforce that investment must be strategically combined with reputation building, particularly through ethical and sustainability credentials, to transform production capacity into sustained market demand within specialty coffee sectors.

CONCLUSION

This research highlights the complexity of the civet coffee production system, where biological, ecological, ethical, and market dynamics are interdependent. The system dynamics model demonstrates that civet health and welfare are central to sustaining population growth and production capacity, while certification and reputation serve as key leverage points for strengthening consumer trust and market absorption. Simulation results confirm that welfare practices, such as improved housing, reduced confinement, and adequate feed supply, not only reduce stress but also enhance long-term productivity. Similarly, investment in certification and reputation building enables producers to overcome stagnant demand and access higher-value markets. However, the system is highly sensitive to ethical scandals and welfare violations, which can rapidly erode consumer confidence. Therefore, policies and strategies for civet coffee development must simultaneously address animal welfare standards, ecological carrying capacity, and supply chain transparency to ensure sustainability. By combining ethical compliance with sustainable farming and certification programs, civet coffee can maintain its international competitiveness while aligning with broader goals of biodiversity conservation and responsible consumption.

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