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A System Dynamics Approach to Strengthening Egg Supply Chain Resilience in Banten

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ABSTRACT

The growing population of Banten Province, projected to surpass 13.5 million by 2035, is expected to drive increasing demand for affordable and accessible sources of staple protein, particularly eggs. Despite producing over 315 million kilograms of eggs in 2023, the regional egg supply chain faces significant challenges, including feed price volatility, poultry mortality, inadequate infrastructure, and fragmented policy coordination. These issues contribute to supply instability and price fluctuations, which in turn affect both producers and consumers. This study employs a system dynamics approach to develop a comprehensive model of the egg supply chain resilience in Banten Province, utilizing stakeholders' perspectives through semi-structured interviews and focus group discussions, as well as mental models derived from comprehensive literature reviews. The constructed model reveals and elucidates critical feedback mechanisms within the egg supply chain, including the hen health investment loop, price-mediated mechanisms loop, and cost-induced constraints loop. The findings highlight the critical importance of policy interventions, particularly in the areas of subsidies, infrastructure development, access to financing, and poultry health initiatives to enhance the resilience of the egg supply chain in Banten. The proposed model offers actionable insights for policymakers and establishes a conceptual framework to support future research on the egg supply chain and food system resilience in Indonesia.

Keywords: *Egg Supply Chain, System Dynamics, Resilience, Causal Loop Diagram*

A. INTRODUCTION

Indonesia is projected to experience a significant increase in population, estimated to exceed 324 million people in 2045, an increase of 53.8 million people compared to the 2020 Population Census results [1], and Banten population is estimated to exceed 13,4 million people in 2035[2].This population surge has a direct impact on increasing food demand, including the provision of affordable and accessible protein sources [3]. The country's inability to fulfill food needs independently often leads to dependence on imports, which is done to maintain price stability and supply [4]. However, dependence on food imports poses a great risk to national economic stability [5]. Based on BPS data, Indonesia still imports poultry eggs with a value reaching US$13.346 million in 2023, up from US$12.209 million in 2022, indicating a high dependence on foreign supplies [6].

Policy synergy between the central and local governments is needed to maintain sustainable food availability. In this context, Banten Province has a strategic opportunity to strengthen its role in national poultry and egg production, with chicken egg production reaching more than 315 million kg in 2023 [7]. Although there was a deficit of around 9,339 tons in April 2024, the high market demand opens up great opportunities for the development of layer farming in this region [8]. By optimizing local potential and production efficiency, Banten can not only meet the increasing domestic demand, but also have the opportunity to become a contributor to poultry egg exports in the future.

A substantial body of research has examined Indonesia's poultry sector, yet notable gaps persist in capturing the complex dynamics of supply chain resilience. A study in East Java employed system dynamics (SD) modeling to analyze the interplay between corn supply, feed mills, and consumer demand, but their approach did not extend to logistics or region-specific consumer behavior [9]. Yuzaria et al. [10] focused on profitability and production trends in West Sumatra, emphasizing feed cost implications but omitting critical infrastructure and policy variables. Meanwhile, another study was carried out to investigate inventory management within Bojonegoro's egg supply chain but failed to incorporate environmental stressors or health considerations [11]. Chapot et al. [12] identified fragmentation in poultry health information-sharing networks but did not link these to supply continuity or resilience. These studies, while valuable, reveal a fragmented understanding of the systemic vulnerabilities inherent in regional poultry supply chains, particularly in rapidly urbanizing provinces like Banten.

Further literature reinforces these limitations. A study was carried out to investigate policies improvement to support chicken industry supply chain in Iran [13], it utilized system dynamics to formulate and prioritize policies to enhance supply chain efficiency in the poultry sector. Hakim et. al. [14] employed the sytem dynamics approach to model hen and feed supply chain to enhance efficiency and resilience. The study identified the obstacle of feed availability, which led to high costs and elevated egg prices. These circumstances hindered the resilience and sustainability of local poultry farming. Meanwhile, Abbasi et. al. [15] combined actor network theory (ANT) and system dynamics to model chicken supply chain, the study aimed to address challenges and improve supply chain sustainability. While their work emphasizes the structural and actor-based dynamics of poultry systems in Malaysia, the current research extends the application of system dynamics modeling to the egg supply chain in Banten.

From a methodological perspective, modelling approach has been widely used to model a sustainable and resilient poultry industry supply chain [16]. System dynamics models are able address the complexity of dynamic system and incorporate inherent feedback loops [17]. Indonesian research on food system resilience focused predominantly on staple like rice [18]–[21] and key protein sources such as chicken [9], [16]. Moreover, these studies did not address the agro-industrial dynamics of Banten Province, which include complex interactions between urban expansion, industrial feed dependencies, and disease risks. This highlights a critical gap in both empirical data and methodological approaches to develop actionable resilience strategies tailored to the province's egg supply chain.

This study aims to address a system dynamics model of the egg supply chain in Banten Province which holistically captures vulnerabilities and feedback mechanisms within egg supply chain system. The model integrates critical variables including feed cost fluctuations, infrastructure, disease outbreaks, and market demand shocks. The research objectives are to identify and analyze key feedback loops influencing egg supply chain and provide policy recommendations to enhance egg supply chain resilience. The findings are expected to support future research on food security and resilience, with a particular focus on the egg supply chain at both local and national levels.

B. LITERATURE

The application of system dynamics methodology has demonstrated significant potential in analyzing and enhancing food security, particularly within the chicken egg production sector. Various studies have adopted this approach to examine crucial aspects of the supply chain and production sustainability. One notable study, focusing on the development of an agropolitan area based on laying hen farming in Lima Puluh Kota Regency, comprehensively modeled the influence of policies and environmental factors on the sustainability of chicken egg production [9]. The system dynamics approach employed in this study, validated using Mean Absolute Percentage Error (MAPE), successfully revealed complex interactions among variables. Similarly, another study specifically investigated the layer chicken feed supply chain in Simeulue Regency using a system dynamics model, emphasizing that feed management is a key factor in the sustainability of laying hen businesses [14].

The validity of the system dynamics method as a tool for policy analysis and complex system planning is further reinforced by a study evaluating the adoption of Enterprise Resource Planning (ERP) in Small and Medium-sized Enterprises (SMEs) in Banyumas [22] and scenario analysis for energy sectors[23]. Despite the differing study objects, the commonality in the system dynamics approach highlights the method's flexibility and capability in understanding system behavior and actor interactions across various contexts.

In the broader context of the chicken industry, the system dynamics approach has proven effective in examining policies aimed at improving the supply chain. Research indicates the importance of policy simulation in enhancing the overall efficiency of chicken farming systems [13]. Furthermore, the integration of Actor-Network Theory with system dynamics to understand the indigenous chicken supply chain opens new interdisciplinary perspectives for comprehending social and technical interactions within farming systems[15]. This approach is highly relevant for application in agropolitan laying hen systems, given the critical importance of coordination among actors in maintaining the sustainability and safety of chicken production, as underscored by a qualitative analysis of health information-sharing networks in Indonesia poultry sector [12].

Aspects of animal health and risk mitigation have also received considerable attention. System dynamics models have been developed for disease management in poultry production, illustrating the complexity of farming systems and their relevance in anticipating risks in the development of chicken farming areas [16]. Moreover, research in the United States has utilized system dynamics models to mitigate the risk of contaminated feed in egg production systems, highlighting the crucial role of risk mitigation in egg production safety policies [24].

Collectively, the system dynamics approach provides a comprehensive framework for modeling and analyzing complex systems, such as the farm-to-fork indigenous chicken value chain [25]. This approach is highly relevant to the agropolitan model, which integrates production, distribution, and consumption. These diverse studies collectively demonstrate that the application of the system dynamics methodology is crucial for designing effective and sustainable policies for food security within the chicken egg sector.

Extending this understanding, the study by Vanany et al. (2021) further exemplifies the utility of system dynamics in enhancing food security in Indonesia. Their research develops a system dynamics model specifically to analyze the supply chain of staple protein sources, including poultry products like chicken meat and eggs. This model intricately captures the interdependencies among corn supply, feed mill production, chicken farming, and consumer demand. Key findings from Vanany et al. (2021) underscore that increasing corn productivity, either through superior seeds or intensive planting systems, and improving chicken feed efficiency can significantly reduce Indonesia's import dependency and stabilize its protein supply. This research offers a robust modeling framework and scenario planning approach that is relevant for studies on egg supply chain resilience in Banten.

Table 1. Reasearch approaches in polutery supply chain

Reference	Author(s)	Method	Objectives
[9]	Vanany et al.	System dynamics modelling	Model food security for staple proteins in Indonesia using system dynamics
[10]	Yuzaria et al.	System dynamics	Analyze chicken egg production system in West Sumatra
[11]	Ramadhan et al.	System dynamics modelling	Improve efficiency of egg supply chain in Bojonegoro
[12]	Chapot et al.	Qualitative network analysis	Analyze health information-sharing networks in Indonesian poultry sector
[13]	Gafi	System dynamics modeling	Study policies for improvement of chicken industry supply chain
[14]	Hakim et al.	System dynamics modeling	Model layer chicken feed supply chain in Simeulue regency
[15]	Ariffin et al.	Actor Network Theory & System dynamics	Develop paradigm for indigenous chicken supply chain
[16]	Galarneau et al.	System dynamics modeling	Model disease management in poultry production
[25]	Abbasi et al.	System dynamics	Creating a fair, healthy, environmentally friendly and sustainable food system to support the farm to fork strategy
[24]	Olufemi et al	System Dynamics and sensitivity analysis	Assessing and reducing the risk of contaminated feed in US egg production systems.

Source: Data Processing

This study addresses a research gap in the analysis of egg supply chains. Previous studies have largely examined limited aspects such as feed availability, production, or actor networks, but none have developed a comprehensive model of egg supply chain resilience, particularly in the regional context of Banten. This study differs from earlier research by constructing a system dynamics model specifically for Banten, integrating mental models derived from established theoretical foundations with perspectives from key stakeholders. The model is represented through a Causal Loop Diagram (CLD), which captures the complex interactions among drivers and barriers of resilience and reflects the actual conditions and dynamic behaviors of the supply chain. The integration of theoretical insights, participatory validation, and system dynamics modeling constitutes the original contribution of this research. In doing so, the study offers a novel framework for examining and enhancing the resilience of the egg supply chain at the regional level.

C. RESEARCH METHOD

This study employed a system dynamics approach utilizing a Causal Loop Diagram analysis to investigate cause and effect relationship to strengthen the resilience of egg supply chain comprehensively in Banten Province. The descriptive design is employed to provide an accurate and systematic overview of the existing conditions of the egg supply chain, encompassing its structure, actors, commodity flow, and encountered challenges [26]. Increasing vulnerability to disruptions highlights the crucial need for a resilient and adaptive supply chain for eggs, a vital protein source, amidst rising feed costs, infrastructure bottlenecks, and policy gaps. The overall reseach metodology adopted in this study is illustrated in Figure 1.

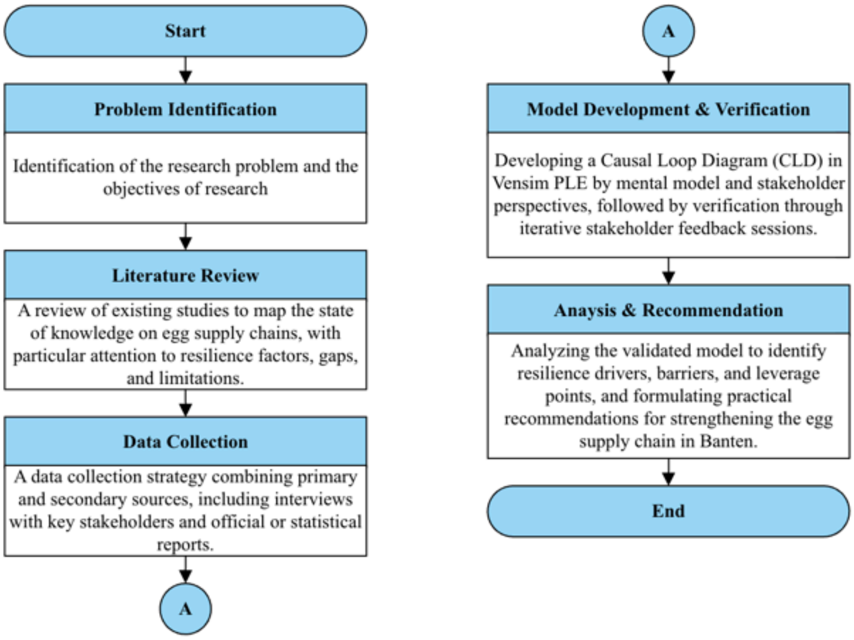

Figure 1. Research methodology flowchart
Source : Data Processing

Figure 1 illustrates the methodological flow adopted in this study. The process begins with problem identification, in which the research problem and objectives are clearly defined, followed by a literature review and data collection from both primary and secondary sources. A Causal Loop Diagram (CLD) was constructed using Vensim PLE, combining mental models with stakeholder perspectives and validated through iterative feedback sessions. The final stage, analysis and recommendation, involves examining the validated model to identify practical strategies for strengthening the egg supply chain in Banten.

Resources and systems frequently intersect and interact through complex feedback mechanisms that encompass numerous variables, function across various temporal and spatial scales, and incorporate human decision-making [27]. The system dynamic methodology excels at identifying feedback loops, simulating the impact of various scenarios, and supporting policy design through a holistic analysis of system behavior over time [28]. This approach provides a comprehensive framework to capture the complex dynamics of egg suppy chain resilience in Banten.

The main unit of analysis in this study covers the entire egg supply chain system in Banten Province, involving all actors and processes from upstream production to downstream distribution to end consumers. This study adopts a data collection strategy by combining primary and secondary data. Primary data was obtained through semi-structured interviews with key stakeholders including poultry farmers, feed suppliers, distributors and local authorities. The interview aimed to identify key factors in egg supply chain including production, feed supply, sales and distribution, government support and funding availability. Secondary data were obtained from literature reviews and reports relevant for egg supply chain across location in Indonesia [29]–[30] and resilience studies on food securities [27][32].

A total of ten respondents participated in the interviews and/or focus group discussions (FGDs), selected through a purposive sampling method to capture diverse perspectives from actors directly involved in the egg supply chain. The participants included three poultry farmers, two feed suppliers, two traders and distributors, a local government official, a consumer and an academic expert in poultry supply chain. This composition ensured that the data reflected both upstream and downstream dynamics of the supply chain, while also incorporating policy and regulatory perspectives. The purposive selection strategy was adopted to ensure that respondents possessed relevant knowledge and practical experience, thereby enhancing the validity and contextual relevance of the information gathered.

The development of mental model was carried out to capture the collective understanding of egg supply chain resilience, its complexity and associated challenges. This preliminary model provided a conceptual framework for illustrating the systemic relationships among critical variables [11][24]. To enhance its applicability and accuracy, the model was subsequently validated by experts, ensuring it aligns with real-world conditions and effectively represents the dynamics of egg supply chain resilience [14].

The mental model was subsequently transformed into a Causal Loop Diagram (CLD) to depict the causal relationships among key variables within the egg supply chain [15]. The CLD highlights reinforcing loops that enhance system performance and balancing loops that inhibit system dynamics [16], for instance, rising feed costs or disease outbreaks that constrain egg supply chain [10]. This comprehensive mapping of feedback mechanisms offers valuable insights into the factors that strengthen the resilience of the egg supply chain.

Validation of Causal Loop Diagram was carried out through the focus group discussion involving stakeholders, supply chain practitioners and academic experts [16][33]. These discussions played a critical role to validating the model accurately represented the system dynamics and interdependencies among key variables within the egg supply chain, thereby enhancing its validity for further analytical use. The validation process also entailed iterative refinement of feedback structures and causal relationships to ensure the model alignment with observed behaviors in the egg supply resilience scenarios.

Furthermore, the finalized Causal Loop Diagram was employed to stimulate a range of scenarios related to interventions aimed at enhancing the reilience of the egg supply chain. For instance, the intervention strategy to reduce the outbreak risk and hen mortality [34]. Another actionable strategy was provided in the model including finansial support variable to increase production and government intervention through the subsidy piolicy [14]. The model provided insights into approaches for addressing key barriers or constraints within the egg supply chain in Banten and enhance its resilience.

To facilitate the development and analysis of the Causal Loop Diagram, this study utilized system dynamics software Vensim PLE version 10.3.0 released by Ventana Systems. The tool enabled the visualization of feedback loop structures and the identification of critical leverage points within the egg supply chain system. Through this analytical approach, the study effectively captured the complex interdependencies influencing egg supply chain resilience and provided a robust foundation for formulating evidence-based and strategic policy recommendations. In conclusion, the application of the Causal Loop Diagram (CLD) methodology provides a comprehensive understanding of the feedback mechanisms that shape the resilience of the egg supply chain in Banten. This approach is intendeed as a basis for formulating actionable policy recommendations, such as targeted subsidies, improved access to financing, and preventive measures against disease outbreaks to enhance the adaptive capacity and stability of the regional egg supply system.

D. RESULT AND DISCUSSION

D.1. Mental model development and verification

Mental models are internal representational frameworks used to understand how complex systems work and assist modellers in representing feedback stuctures [35]. In the system dynamics approach, developing accurate mental models is crucial for identifying the underlying structure of problems and the dynamic relationships between variables within a system [33]. These models serve as a tool for stakeholders to articulate their perceptions of the cause-and-effect relationships underlying system behavior [22]. In the context of the egg supply chain in Banten, the development of mental models is an important basis to capture system dynamics models based on the perspectives of the stakeholders involved.

The mental model was developed through extensive review of relevant studies or literature [29]–[30] and further substantiated through semi-structured interviews involving key stakeholders within egg supply chain in Banten. Furthermore, experts perpectives are essential to confirm and validate the mental model to ensure that it reflects the actual condition of the egg supply chain system. The validation process involved experts with more than seven years in poultry industries, supply chain practitioners and academics. Insights derived from the interviews were identified, several system perceptions were utilized to develop research model. The model validation procedure included structured stakeholder interviews focused on reviewing and refining the Causal Loop Diagram constructed from the mental model.

Each feedback loop within the Causal Loop Diagram was critically assessed and either validated or revised based on stakeholders' feedback. This process resembled a series of Focus Group Discussions (FGDs), where diverse expert perspectives were integrated to enhance the model's reliability and representativeness. Several rounds of FGDs were conducted throughout the modeling process, from the initial mental model development to the final validation phase. The integration of the mental model with stakeholders insights resulted in the formulation of a dynamic research hypothesis. This hypothesis is intended to generate representative outcomes derived from the developed model, reflecting the interactions among key variables and the causal relationships.

D.2. Actor Analysis

Actor analysis plays an important role in understanding the dynamics that occur in the egg supply chain, as well as identifying the interests, challenges, and objectives of the various stakeholders involved [36]. This understanding is gained through mapping the roles and perspectives of each actor, from farmers, sellers to consumers, and policymakers. Therefore, the results of the multi-stakeholder analysis conducted in this study are presented Table 2 to summarize the responsibilities, perceptions of problems, and objectives of the main actors involved in the egg supply chain system in Banten Province.

Table 2. Egg supply chain actor analysis

Actor	Roles/Responsibilities	Problem Perception	Objectives
Local government	Regulates food safety, provides subsidies, monitors supply chains	Market instability, lack of data for interventions	Support food security, stabilize prices, and assist stakeholders with policies
Farmer	Produces and supplies eggs; maintains poultry health and productivity	Input cost fluctuations, disease outbreaks, and market price volatility	Improve production efficiency, ensure stable income, and reduce supply risks
Distributor	Transports eggs from farms to markets or retailers	Disruptions due to poor infrastructure or fuel costs	Ensure timely delivery and maintain chain integrity
Feed supplier	Supplies poultry feed to farmers	Variability in raw material prices, logistics disruptions	Ensure steady demand and maintain competitive pricing
Retailer	Sells eggs directly to consumers	Stockouts, price sensitivity	Maintain consistent supply and manage profit margins
Consumer	Purchases and consumes eggs	Concerned with price increases, egg quality, and availability	Access affordable, safe, and reliable egg supply

Source : Data Processing

The egg supply chain system in Banten consists of various key actors who have specific roles and face a variety of challenges. Egg farmers are central to the production process, as they are responsible for maintaining the health of poultry and the continuity of egg supply. In practice, they face several critical challenges such as spikes in feed prices, disease threats, and market price instability, which can directly impact the sustainability of their businesses and income. Therefore, improving operational efficiency, income stability, and production risk mitigation are their primary focuses. Feed suppliers play a supporting role by providing essential raw materials to farmers, although they are also affected by fluctuations in raw material prices and distribution barriers, necessitating the maintenance of supply continuity and competitive pricing.

Along the distribution chain, the role of intermediaries is carried out by distributors and retailers. Distributors are responsible for moving products from production sites to markets or retail outlets, but they often face infrastructure challenges and high transportation costs that can hinder logistics efficiency and reduce product quality. Meanwhile, retailers who interact directly with consumers frequently encounter supply irregularities and price sensitivity from customers. Their efforts are focused on ensuring stable product availability and optimizing profit margins.

On the other hand, consumers and government agencies also hold strategic positions within this network. Consumers expect safe, high-quality, easily accessible, and affordable eggs, but they are vulnerable to the impacts of price fluctuations and inconsistent supply. The government and policymakers are responsible for regulating and maintaining system stability through the provision of policies, regulations, and other forms of intervention. However, these roles are not without challenges, such as the lack of real-time data and insufficient policy response capacity in emergency situations. Therefore, the government's primary objectives include strengthening food security, price control, and protecting all links in the egg supply chain in this region.

D.3. Systems diagram framework

A system diagram was used to visually illustrate the complex dynamics that shape interactions and feedback patterns in the egg supply chain in Banten. This diagram is an important tool in the system dynamics approach, as it enables the mapping of causal relationships between various system components such as production capacity, feed availability, market demand fluctuations, price changes, and the role of government intervention. By presenting the system structure comprehensively, the diagram shows how each variable influences one another over time, while also highlighting strategic points where policies can be implemented to strengthen system resilience.

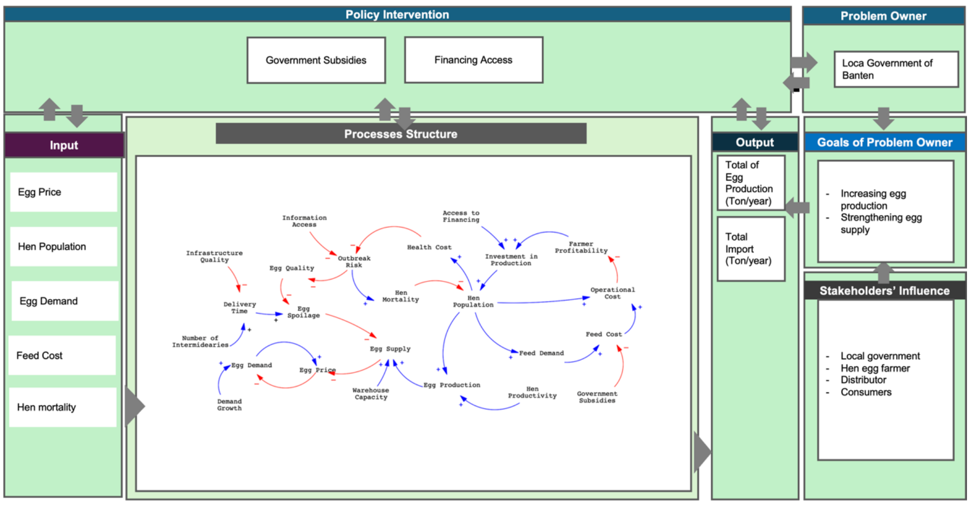

Figure 2. System diagram of egg supply chain in Banten
Source : Data Processing

The system diagram used in this study presents a comprehensive mapping of the dynamics of the egg supply chain in Banten Province, emphasizing the interrelationships between variables that directly impact egg production and distribution. This diagram is based on a feedback framework, illustrating how variables such as egg prices, chicken population size, demand levels, feed costs, and chicken mortality rates interact throughout the entire production process. At the core, it is evident that the productivity of laying hens and the level of investment in production are the primary drivers of egg supply, while both factors are significantly influenced by access to financing and government subsidies. This situation makes supportive policies an important tool in strengthening farmers' production capacity and reducing their vulnerability to market changes.

Additionally, the internal structure of the diagram shows that feedback mechanisms within the system can work in a mutually reinforcing or balancing manner. For example, increased consumer demand for eggs can lead to price increases, which in turn trigger increased investment by farmers to expand production. However, this process can also be hindered by various factors such as high operational and feed costs, high chicken mortality rates, and health care costs, all of which contribute to declining business profits. In addition, there are also external variables such as infrastructure conditions, the number of distribution intermediaries, and delivery duration that affect product damage risk and egg quality decline, thereby impacting supply stability and consumer satisfaction levels.

Furthermore, this diagram establishes the Banten Regional Government as the party primarily responsible for addressing systemic issues in this sector, with a primary focus on increasing production and strengthening the supply chain structure. The roles of other actors such as farmers, distributors, and consumers are also significant in shaping the dynamics of the system. In this context, indicators such as total production and import volume are used as benchmarks to assess the overall performance of the system. Therefore, this diagram not only helps policymakers understand the interconnections between variables in depth but also serves as a strategic tool in designing appropriate policy interventions, such as expanding access to financing and providing subsidies, to enhance the resilience and stability of the egg supply chain in Banten.

D.4. Causal Loop Diagram

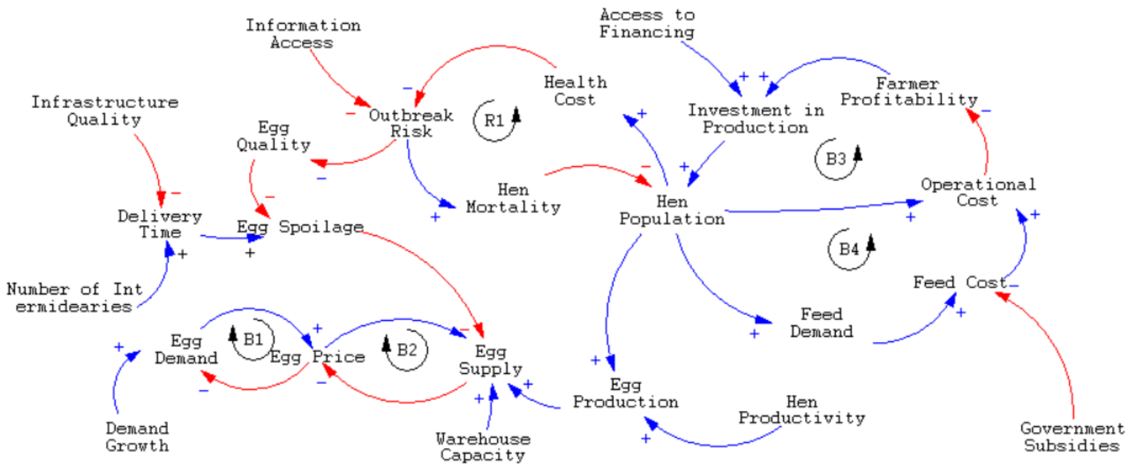

Figure 3. Causal Loop Diagram of egg supply chain in Banten
Source : Data Processing

The Causal Loop Diagram (CLD) visualizes the dynamic relationships and feedback loops within the egg supply chain system in Banten. It demonstrates how various interrelated factors—ranging from production capacity and market demand to health risks and infrastructure—collectively influence the system's performance. Each arrow in the diagram signifies a causal link: a "+" sign means the variables move in the same direction, while a "–" sign indicates an inverse relationship. These feedback structures are essential for identifying leverage points for improving system resilience and informing policy decisions. At the heart of the diagram is the egg production cycle, which is influenced by hen population, hen productivity, and investment in production. Access to financing and government subsidies enhance farmers' ability to invest in production, leading to an increase in hen population and egg output. A larger hen population generates more egg supply, which helps meet consumer demand and improves the stability of the supply chain. As egg production increases, it supports warehouse capacity and reinforces system growth, an example of a reinforcing loop that enables positive system expansion when properly supported.

Loop R1 – Reinforcing Loop: Hen Health Investment Feedback

Loop R1 represents a reinforcing feedback mechanism that illustrates the relationship between poultry health investment and flock stability. An increase in health-related expenditures (health cost)—such as veterinary services, vaccinations, and nutritional feed—contributes to a reduction in outbreak risk. As disease outbreaks become less frequent, hen mortality declines, which leads to a larger and more stable hen population. A growing hen population increases the need for consistent health management, thereby reinforcing the allocation of health-related expenditures to maintain system productivity.

Causal chain:

Health Cost (–) → Outbreak Risk (+) → Hen Mortality (–) → Hen Population (+) → Health Cost

This loop demonstrates how proactive investment in poultry health fosters a virtuous cycle that enhances the resilience of the egg supply system. By mitigating disease risk and reducing mortality, farmers are able to sustain a productive flock, thereby supporting continuous egg production. Conversely, insufficient investment in health management increases the risk of outbreaks, which can trigger systemic disruptions in the supply chain due to rising mortality and declining productivity.

Loops B1 and B2 – Balancing Loops: Price-Mediated Demand and Supply Stabilization

Loops B1 and B2 together represent the core market balancing mechanisms in the egg supply chain, where price functions as the central regulatory variable between supply and demand. Loop B1 describes how changes in egg demand influence egg prices, which in turn affect demand itself. Specifically, an increase in egg demand tends to drive prices upward. However, as prices rise, consumer demand tends to decrease due to price sensitivity, thus counteracting the initial increase. This creates a balancing feedback loop, in which the system resists unbounded growth in demand by adjusting price as a moderating factor.

Loop B2 captures the inverse relationship from the supply side. A decline in egg supply caused, for example, by production constraints or distribution inefficiencies leads to an increase in egg prices. Higher prices act as a signal for producers to increase supply, as the market becomes more profitable. This forms another balancing loop, where the system responds to scarcity with a supply-side adjustment, thereby dampening fluctuations in availability.

Causal chains:

B1: Egg Demand (+) → Egg Price (–) → EggDemand

B2: Egg Supply (–) → Egg Price (+) → Egg Supply

Together, these two loops reflect the self-regulating dynamics of market equilibrium, where price acts as the key feedback variable. While B1 functions by tempering excessive demand through price increases, B2 functions by incentivizing supply growth when prices rise due to scarcity. These interlinked balancing loops are crucial in maintaining short-term market stability and preventing extreme volatility. However, their effectiveness depends on how quickly producers and consumers respond to price signals, and whether market distortions, such as subsidies, hoarding, or information asymmetry are present. Recognizing the interaction of B1 and B2 is essential for designing policies that ensure price stability and a resilient egg supply chain.

Loops B3 and B4 – Balancing Loops: Cost-Driven Constraints on Production Expansion

Loops B3 and B4 jointly illustrate the internal cost-related balancing mechanisms that moderate the expansion of hen populations in the egg production system. While profitability and investment play a key role in reinforcing production capacity, they are simultaneously constrained by escalating operational costs—particularly feed-related expenses—which act as natural stabilizers within the system.

Loop B3 traces the impact of increased hen population on feed demand. As hen numbers grow, feed consumption rises, leading to an increase in feed costs. Higher feed costs elevate overall operational expenses, which in turn reduce farmer profitability. This decline in profitability limits the capacity or willingness of farmers to reinvest in expanding production. As investment in production decreases, growth in the hen population is subsequently restrained. This loop serves as a cost-based balancing mechanism, preventing unchecked expansion due to resource constraints.

Loop B4 represents a simplified version of the same dynamic, where the growing hen population leads directly to increased operational costs (beyond just feed), which diminishes farmer profitability and thereby restricts further investment in production. As with B3, this results in a self-regulating mechanism that inhibits further growth in hen population when profitability declines due to rising costs.

Causal chains:

B3: Hen Population (+) → Feed Demand (+) → Feed Cost (+) → Operational Cost (–) → Farmer Profitability (+) → Investment in Production (+) → Hen Population

B4: Hen Population (+) → Operational Cost (–) → Farmer Profitability (+) → Investment in Production (+) → Hen Population

Both B3 and B4 loops act as economic stabilizers by curbing excessive growth in the hen population through the feedback effects of rising costs and declining profitability. Within these loops, different stakeholders play critical roles. For instance, the government may intervene through subsidies or policies that reduce feed costs, while farmers respond by adjusting their investment decisions in flock expansion, and distributors influence cost structures through logistics and market access. Although external interventions such as subsidies or improved feed efficiency could ease the financial pressures, the presence of these loops highlights the importance of managing cost dynamics collaboratively across stakeholders. If left unaddressed, escalating operational costs could discourage farmer investment, constrain production, and ultimately weaken the resilience of the entire egg supply chain.

In conclusion, the CLD highlights the complex, interconnected nature of the egg supply chain in Banten. It identifies both reinforcing loops that can lead to growth and balancing loops that prevent overexpansion or collapse. By analyzing these feedback loops, policymakers and stakeholders can pinpoint where to intervene whether through subsidies, infrastructure improvements, health support, or market regulation to enhance the system’s resilience and ensure a reliable, efficient supply of eggs for the region.

E. CONCLUSION

This study designed a comprehensive system dynamics approach to investigate the egg supply chain resilience in Banten Province, with a highlighting on the complex interaction between components within the system including barriers and drivers such as outbreak risk, price fluctuation, financing access and government support. The Causal Loop Diagram (CLD) developed illustrates the feedback loops between variables, both reinforcing and balanced loop. It identified a total of five feedback loops comprising one reinforcing loop and four balancing loops. The reinforcing loop, labeled as the Hen Health Investment Feedback Loop, illustrates the positive cyclical effects of health-related investments on poultry stability. The balancing loops include B1 and B2, which represent price-mediated mechanisms that regulate demand

and supply equilibrium, and B3 and B4, which highlight cost-induced constraints that limit production expansion.

This study provides a conceptual framework for systematically understanding and analyzing the resilience of the egg supply chain in the regional context of Banten, emphasizing the complex interactions among key drivers and barriers including disease outbreaks, price fluctuations, access to finance, and government support. The findings imply that resilience in the egg supply chain is strongly influenced by the interplay of costs, profitability, and health management, underscoring the need for coordinated interventions among stakeholders. Practical recommendations include expanding farmers' access to financial resources, strengthening government support through targeted subsidies, and enhancing disease prevention measures. These strategies can help balance growth, mitigate risks, and improve the adaptive capacity of the supply chain. Furthermore, the conceptual model developed here provides a foundation for future research to extend into quantitative simulations using stock and flow diagrams, enabling policymakers to test alternative policy scenarios and evaluate their long-term impacts on supply chain resilience.

REFERENCES

[1] BPS, *Indonesia Population Projection Based on Census 2020*. 2023.

[2] BPS Provinsi Banten, *Proyeksi Penduduk Kabupaten/Kota Provinsi Banten 2020-2035*, 1st ed. Serang: Badan Pusat Statistik Provinsi Banten, 2023.

[3] N. C. Wibawa, H. Ardini, G. Hermawati, R. N. Firdausa, K. B. Anggoro, and R. Wikansari, "Analisis Impor Beras Di Indonesia Dan Faktor-Faktor Yang Memengaruhi Impor Beras," *J. Econ.*, vol. 2, no. 2, pp. 574–585, 2023, doi: 10.55681/economina.v2i2.337.

[4] A. K. Putra, A. Rafi, R. P. Darmawan, and R. Wikansari, "Peran pemerintah meningkatkan perdagangan internasional khususnya ekspor," *J. Ilmu Ekon.*, vol. 2, no. 3, pp. 1–10, 2023, doi: 10.59827/jie.v2i3.94.

[5] X. Wang, L. Ma, S. Yan, X. Chen, and A. Growe, "Trade for Food Security: The Stability of Global Agricultural Trade Networks," *Foods*, vol. 12, no. 2, 2023, doi: 10.3390/foods12020271.

[6] Rosseno Aji Nugroho, "RI Rajin Impor Telur, Dari India, Jerman Sampai AS!," CNBC Indonesia.

[7] Badan Pusat Statistik, "Produksi Telur Unggas dan Susu Sapi Menurut Provinsi (kg), 2023.," Badan Pusat Statistik.

[8] Mulyana, "Banten kekurangan telur ayam 9.339 ton dipasok dari Blitar," Antara News.

[9] I. Vanany, G. Hajar, N. M. C. Utami, and L. M. Jaelani, "Modelling food security for staple protein in Indonesia using system dynamics approach," *Cogent Eng.*, vol. 8, no. 1, 2021, doi: 10.1080/23311916.2021.2003945.

[10] D. Yuzaria, F. Fitrimawati, and M. Ikhsan Rias, "Analysis system dynamic of chicken egg production system: Case in West Sumatra Indonesia," *BIO Web Conf.*, vol. 81, 2023, doi: 10.1051/bioconf/20238100030.

[11] J. B. Ramadhan, G. H. Rahmawan, T. N. Rahmah, and S. F. A. Wati, "Model Sistem Dinamis Dalam Meningkatkan Efisiensi Rantai Pasok Telur Ayam Di Bojonegoro," *Koloni*, vol. 3, no. 2, pp. 261–271, 2024.

[12] L. Chapot *et al.*, "A qualitative analysis of health information-sharing networks in the Indonesian poultry sector," *Prev. Vet. Med.*, vol. 219, no. August, p. 106003, 2023, doi: 10.1016/j.prevetmed.2023.106003.

[13] E. G. Gafi, "A System Dynamics Model for Studying the Policies of Improvement of Chicken Industry Supply Chain," no. October 2018, 2022, doi: 10.4018/IJSDA.2018100102.

[14] L. Hakim, Alfianus, Indra, Fajri, and Monalisa, "System dynamics modeling of the layer chicken feed supply chain in Simeulue regency," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1476, no. 1, 2025, doi: 10.1088/1755-1315/1476/1/012070.

[15] A. S. Ariffin, I. A. Abbasi, A. G. Hanafi, M. A. Md Sin, and H. Hashom, "Forging Futures: An Emerging Paradigm for Indigenous Chicken Supply Chain with Actor Network Theory and System Dynamics," *Int. J. Acad. Res. Bus. Soc. Sci.*, vol. 14, no. 8, pp. 187–200, 2024, doi:

10.6007/ijarbss/v14-i8/22381.
[16] K. D. Galarneau, R. S. Singer, and R. W. Wills, “A system dynamics model for disease management in poultry production,” *Poult. Sci.*, vol. 99, no. 11, pp. 5547–5559, 2020, doi: 10.1016/j.psj.2020.08.011.
[17] J. D. Sterman, *Systems Thinking and Modeling for a Complex World*, vol. 34, no. 1. USA, 2000. [Online]. Available: http://www.lavoisier.fr/notice/frJWOAR6SA23WLOO.html
[18] J. M. M. Aji, “Linking Supply Chain Management and Food Security: A Concept of Building Sustainable Competitive Advantage of Agribusiness in Developing Economies,” in *E3S Web of Conferences*, EDP Sciences, Jan. 2020. doi: 10.1051/e3sconf/202014206005.
[19] Y. Fristin and F. Supanto, “Development Model of Rice Supply Chain Management to Ensure Self-Sufficiency and Food Security,” *J. Bisnis dan Manaj.*, vol. 8, no. 2, pp. 353–366, 2021, doi: 10.26905/jbm.v8i2.6320.
[20] P. Hilda Anugrah, J. Sutrisno, S. Marwanti, U. Amalia Nadifta, and N. Indah, “Analysis of Rice Supply Chain Management Related to Performance and Sustainability of Food Security Program in Central Java,” *Univers. J. Agric. Res.*, vol. 11, no. 3, pp. 525–536, 2023, doi: 10.13189/ujar.2023.110303.
[21] E. Suryani, R. Agus Hendrawan, T. Mulyono, and L. P. Dewi, “System Dynamics Model to Support Rice Production and Distribution for Food Security,” *J. Technol. Sci. Eng.*, vol. 68, no. 3, pp. 2180–3722, 2014, [Online]. Available: www.jurnalteknologi.utm.my
[22] A. Y. Ramdhani, L. F. Lishobrina, A. Tirta, and J. Segara, “A System Dynamics Approach to ERP Adoption in SMEs : A Case Study of Banyumas,” vol. 20, no. 1, pp. 238–248, 2025.
[23] A. Y. Ramdhani, I. A. T. Munikhah, H. Q. Karima, and M. I. Faturohman, “Scenario Analysis of Indonesian Biodiesel Policy for Reducing GHG Using System Dynamics,” vol. 6869, 2021, doi: 10.23917/jiti.v24i1.8353.
[24] O. I. Olufemi, O. Ayeni, and O. E. Olagoke-Komolafe, “A Systems Dynamics Model to Mitigate the Risk of Contaminated Feed in Egg Production Systems in the USA,” vol. IX, 2025, doi: 10.47772/IJRISS.
[25] I. A. Abbasi, H. Ashari, A. S. Ariffin, and I. Yusuf, “Farm to Fork: Indigenous Chicken Value Chain Modelling Using System Dynamics Approach,” *Sustain.* , vol. 15, no. 2, pp. 1–19, 2023, doi: 10.3390/su15021402.
[26] E. Wakhid, W. Seto, and Y. N. Muflikh, “Kinerja Rantai Pasok Telur Ayam Ras Pada Peternakan Ayam Sukses, Kabupaten Pati: Pendekatan Fscn Supply Chain Performance of Broiler Chicken Eggs At the Sukses Chicken Farm, Pati Regency: Fscn Approach,” vol. 7, no. 4, pp. 1341–1354, 2023, [Online]. Available: https://doi.org/10.21776/ub.jepa.2023.007.04.13
[27] B. L. Turner, H. M. Menendez, R. Gates, L. O. Tedeschi, and A. S. Atzori, “System dynamics modeling for agricultural and natural resource management issues: Review of some past cases and forecasting future roles,” *Resources*, vol. 5, no. 4, 2016, doi: 10.3390/resources5040040.
[28] J. Sterman, “System Dynamics: systems thinking and modeling for a complex world. in: ESD Internal Symposium, de 29 a 30/05/2002, Cambridge, MA,” *Eng. Syst. Div. Work. Pap. Ser.*, p. 31, 2002, [Online]. Available: https://dspace.mit.edu/handle/1721.1/102741
[29] D. K. Purnamasari, Syamsuhaidi, Sumiati, and G. M. A. Alfian, “Produktivitas dan Efisiensi Pakan Ayam Ras Petelur Dengan Mengefisiensikan Penggunaan Konsentrat,” *J. Ilmu dan Teknol. Peternak. Indones.*, vol. 8, no. 2, pp. 112–119, 2022.
[30] A. Bafadal *et al.*, “Analisis Rantai Pasok Telur Ayam Ras Laying Eggs Supply Chain Analysis,” *J. Ilmu dan Teknol. Peternak. Trop.*, vol. 9, no. 1, pp. 55–61, 2021, doi: 10.33772/jitro.v9i1.20180.
[31] M. Sun *et al.*, “The mechanism of egg production improvement in laying hens before and after molting revealed by transcriptome and metabolome integration,” *Poult. Sci.*, vol. 104, no. 7, p. 105125, 2025, doi: 10.1016/j.psj.2025.105125.
[32] J. Stone and S. Rahimifard, “Resilience in agri-food supply chains: a critical analysis of the literature and synthesis of a novel framework,” *Supply Chain Manag.*, vol. 23, no. 3, pp. 207–238, 2018, doi: 10.1108/SCM-06-2017-0201.
[33] Y. Barlas, “Formal aspects of model validity and validation in system dynamics,” *Syst. Dyn. Rev.*, vol. 12, no. 3, pp. 183–210, 1996, doi: 10.1002/(sici)1099-1727(199623)12:3<183::aid-sdr103>3.3.co;2-w.
[34] I. Ismoyowati, E. Tugiyanti, D. Indrasanti, N. A. Setianto, and V. Armelia, “Developing Strategy

to Reduce the Mortality of Native Chicken using Qualitative Modeling," *Bul. Peternak.*, vol. 46, no. 1, p. 54, 2022, doi: 10.21059/buletinpeternak.v46i1.70195.
[35] I. P. Guma, A. S. Rwashana, and B. Oyo, "Food Security Indicators for Subsistence Farmers Sustainability," *Int. J. Syst. Dyn. Appl.*, vol. 7, no. 1, pp. 45–64, 2017, doi: 10.4018/ijsda.2018010103.
[36] B. Enserink *et al.*, *Policy Analysis of Multi-Actor Systems*, no. August. 2022. doi: 10.5074/t.2022.004.